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The Editors will be glad to receive original papers or other contributions intended for publication in Parts III and IV of Volume I.

Articles should be sent to T. B. WOOD, M.A., University Department of Agriculture, Cambridge: for Part III not later than May 1st, and for Part IV, not later than August 1st, 1905.

All communications must be typed or written on one side of the paper. A wide margin equal to at least ¼ of the page, should be left.

VOLUME I MAY, 1905 PART II

VARIATION IN THE COMPOSITION OF COWS' MILK.

A RÉSUMÉ OF RECENT EXPERIMENTAL WORK IN GREAT BRITAIN.

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THE object of the present communication is to collect together and compare the data obtained in the principal investigations which have been carried out in this country during the past five years into the variations in composition of the milk of the cow. The results of many of these experiments have been published only in annual reports or as special bulletins with limited and more or less exclusively local circulation.

For this latter reason it is impossible for the writer to be absolutely certain that all experiments which might fairly claim notice have been included in the *résumé*, but every effort has been made to render it as complete as possible in this respect. Further, in view of the admitted difficulty in obtaining samples of milk representative of the bulk from which they are taken, even when the sample is drawn immediately on the completion of milking, no account has been taken of published data based on samples taken under other conditions.

The fact has also not been overlooked that many experiments not alluded to in this summary have been carried out from time to time by practical farmers on their own farms, and reported in more or less detail in the agricultural periodicals; but, whilst not intending thereby to impugn the accuracy of any of these experiments, it has been thought advisable to limit the survey to such experiments as have been carried out by trained investigators connected with agricultural educational institutions or the great agricultural societies.

The experiments reviewed were carried out in or subsequent to the year 1900. This period has been adopted in view of the fact that a more or less complete summary of the data obtained up to that year is generally available in the Report of the "Milk Standard" Committee[1] appointed in that year by the Board of Agriculture, and in the Minutes of Evidence[1] on which that report is based. Moreover much of the subsequent experimental work has been occasioned or considerably influenced by the regulations for the sale of milk introduced by the Board as the outcome of the deliberations of that Committee.

The evidence given before the Committee revealed a wide disparity of opinion on many important points. Further it is noticeable that very little precise information based upon samples drawn in the cowhouse immediately after the milking was at that time available concerning the diurnal variations in the composition of the milk of individual cows, and even of the mixed milk of herds.

This fact had already attracted attention, and led to the carrying out, first in 1900 by Mr Herbert Ingle, of the (then) Yorkshire College, and subsequently by other investigators in connexion with similar institutions, of the investigations into the nature and extent of these variations, and the causes to which they are attributable, which form the subject of the present communication.

A list of the investigations dealt with—numbered for convenience of reference—will be found on p. 175, together with data which may be helpful in comparing the results. Particulars are also given in this table of the sources from which the results have been derived.

In the Scottish investigations (9, 11)[2] practically all the cows were of Ayrshire breed, but in all other cases the cows were of shorthorn breed.

It will be noted that the conditions under which the various experiments were carried out (*e.g.* in respect of season, times of milking, etc.) differed widely, so that it is impossible to institute a fair comparison throughout of the results obtained in the different investigations. In this connexion the writer can indeed do little more than direct attention to any such differences, and suggest the degree of importance which, in his opinion, should be attached to each.

In the following pages the chief influences which have been investigated in the different experiments are dealt with in separate sections. It is hoped that a more interesting and useful survey of

[1] Published in 1901.

[2] Nos. 9, 11 in the list on p. 175. This mode of reference to the individual investigations is employed throughout the *résumé*.

the results has thereby been arrived at than could be obtained by reviewing each investigation separately. For connected accounts of each investigation reference must hence be made to the original memoirs.

METHODS OF ANALYSIS.

The analysis of the samples has in practically every case been limited to estimations of the proportions of fat and total solids.

The *fat* has almost invariably been estimated by the Gerber method, and opinion is unanimous as to its accuracy and reliability. Ingle records however (1 *a*), that the use of formaldehyde as a preservative renders the curd much more difficult of solution in the mixture of sulphuric acid and amyl alcohol. He subsequently used an ammoniacal solution of potassium dichromate for preservative purposes. Collins (4 *a*) used either a mixture of chloroform and ether or a mixture of chloroform and alcohol containing about 1 per cent. of formaldehyde. The small quantity of the latter used had no disturbing effect.

The *total solids* have in many cases been estimated directly by evaporation, but more frequently the more rapid indirect method based on Richmond's well-known formula, and involving only determinations of the fat-content and specific gravity of the sample, has been used. The accuracy of this method, as compared with the direct estimation, has apparently been tested in comparatively few cases, but all agree that the concordance is usually very close, the difference between the two values rarely exceeding ·1—·2 per cent., the lower value being usually that obtained by the indirect method.

Reference may also be made here to the investigations carried out in the Government laboratories into the possibilities of error in the analysis of sour milks by the ordinary methods[1]. It is found that the errors are almost entirely confined to the estimation of the solids-not-fat, for which low results are obtained owing to the formation of volatile products by fermentation. It has further been found that the deficiency can be calculated with fair accuracy from the amounts of alcohol, volatile acids, and ammonia present in the sample.

A passing reference may also be made to the further investigations of Thorpe and his assistants into the variations in and interdependence of the physical and chemical criteria of the fat of butter, dealt with in

[1] Thorpe, *Journ. Chem. Soc. Trans.* 1905, 206.

the analysis of the same[1], although they do not strictly fall within the scope of the present review.

INFLUENCE OF INTERVAL BETWEEN SUCCESSIVE MILKINGS.

This question has been definitely investigated in two separate experiments, viz., at Garforth in 1902 (1 c), and at Cambridge in 1903 (8).

In the Garforth experiment the effect of a change from a night interval of 15 hours and a day interval of 9 hours to intervals of 12½ and 11½ hours respectively was investigated with five cows. The experiment extended over nine weeks, the more unequal intervals being employed during the first two and the last three weeks [(*a*) and (*c*) in table below].

In the Cambridge experiment three cows were milked at equal intervals, and samples of their milk taken at each milking for 14 days (*a*), after which the night interval was extended to 16 hours—the day interval thus becoming 8 hours—and sampling continued for 14 days longer (*b*).

The results of the two experiments are summarised in the following table:

Experiment	Ratio Day : Night Interval	Morning		Evening		Ratio a.m. : p.m.		
		Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %	Yield
Garforth (*a*)...	1 : 1·67	2·87	9·03	4·26	9·00	1 : 1·484	1 : 0·997	1·480 : 1
,, (*b*)...	1·09	3·18	8·95	3·80	8·99	1·195	1·005	1·182
,, (*c*)...	1·67	2·94	8·83	4·40	8·79	1·497	0·995	1·382
Cambridge (*a*)	1 : 1·00	3·64	8·81	3·45	8·92	1 : 0·948	1 : 1·012	1·051 : 1
,, (*b*)	: 2·00	2·33	8·97	4·47	8·92	1·918	: 0·994	1·486

The results of the two experiments are strikingly similar in every respect, and clearly confirm the commonly accepted opinion that, apart from the influence of the individuality of the animal, the quantity and richness in fat of the milk yielded at any particular milking by a well-nourished cow in normal health are very largely determined by the length of time which has elapsed since the previous milking.

[1] Thorpe, *Journ. Chem. Soc. Trans.* 1904, 248.

The effect of the interval on the proportion of solids-not-fat is apparently not very pronounced, but it may be noted that in the two experiments mentioned the milk was in both cases richest in this respect after the longer interval, and this would indeed appear to be a fairly general rule.

Further confirmation of these conclusions is afforded by a comparison of the data obtained in the different investigations where different intervals were employed (cf. Table, p. 175). For this purpose the following table has been compiled from the available data, giving the average a.m. : p.m. ratio of the percentages of fat and solids-not-fat respectively for different degrees of inequality of the intervals between successive milkings.

Ratio Day : Night Interval	Ratio, a.m. : p.m.		Approximate No. of Samples	No. of Herds
	Fat %	Solids-not-Fat %		
1 : 1·0	1 : 1·015		400	19
		1 : 1·012	14	1
1·1	1·060		270	3
		0·998	270	3
1·3	1·157		126	3
		0·989	93	2
1·6	1·430		400	2
		0·985	300	1
2·4	1·406	0·966	30	1

It would thus appear that, in the case of herds of cows milked at equal intervals of 12 hours, the milk secreted during the day interval is only very slightly richer in fat and in solids-not-fat than that secreted during the night; but that the greater the inequality of the intervals between the milkings, the more unequal is the distribution of the fat and solids-not-fat between the two milkings, the morning milk (after the longer interval) becoming progressively poorer in fat but richer in solids-not-fat as the interval increases, whilst the quality of the evening milk varies in exactly the opposite manner.

The further question crops up in this connexion as to whether the mean results *for the whole day* are affected by the intervals between the two milkings. The only evidence available on this point from the experiments under review is that furnished by Ingle's experiment at Garforth referred to on p. 152. The mean results for the whole day in each of the three periods of the experiment are given in the following

table. The figures in brackets are the corresponding data for another group of four cows, which were milked regularly throughout the nine weeks at the more unequal intervals, and serve to indicate the allowance that must be made for the "normal" changes in the yield and quality of the milk during the periods in question.

	Ratio Day : Night Interval	Mean Daily Results		
		Yield	Fat %	Solids-not-Fat %
Period 1 (2 weeks)...	1·67	164·8 (164·7)	3·43 (3·08)	9·02 (8·94)
Period 2 (4 weeks)...	1·09	150·4 (144·1)	3·45 (3·01)	8·97 (8·80)
Period 3 (3 weeks)...	1·67	133·8 (132·1)	3·55 (3·10)	8·81 (8·77)

On comparing the records of the two groups it will be seen that the change to more equal intervals had but little effect on the mean daily yield and composition, such small difference as can be detected being in favour of the more equal intervals.

Influence of Day and Night.

Apart from the influence of the intervals between milkings, it would appear quite possible that the alternation of day and night may exert a specific influence on the milk secretion.

This is evident from an experiment carried out by Ingle at Garforth in 1900 (1 *a*). Three cows—housed day and night—were milked at intervals of six hours for four days, and samples taken at each milking. The following table gives the mean results obtained:

	Time of Milking			
	5 a.m.	11 a.m.	5 p.m.	11 p.m.
Fat %..................	2·8	3·6	3·5	3·0
Milk Yield (Total)...	40 lb.	23·5 lb.	24 lb.	24 lb.
,, ,, (Ratio)...	1·0	·59	·60	·60
Yield of Fat (Total)	1·1	·85	·82	·70
,, ,, (Ratio)	1·0	·77	·75	·64

In this case it is clear that the milk secreted between 5 a.m. and 5 p.m. was much richer in fat than that secreted in the night, but that

the most abundant secretion took place during the night. The experiment is not quite conclusive, however, for, as Ingle subsequently pointed out[1], "it is quite possible that the cows used had become accustomed to produce richer milk in the day-time by the long period during which they had been milked at the unequal intervals" (15, 9 hours), "and that for four days this habit still persisted."

In this connexion the results obtained in the Northumberland experiments with the Offerton herd (4 *b*) may be quoted. These cows were milked daily at 5 a.m., 1 p.m., and 6 p.m. (*i.e.*, after intervals of 11, 8, and 5 hours respectively), and the mean yield and composition of the milk obtained at each milking on the six days throughout three months on which samples were taken were as follows:

	Morning	Noon	Evening
Yield (pints)	138	79	43
Fat %	3·36	4·26	4·16
Solids-not-Fat %	8·91	9·00	9·21

It is noticeable that the yield at 5 a.m., after 11 hours' lactation, was greater than the sum of the yields at the two following milkings representing the produce of 13 hours' lactation; and further, that the percentage of fat was highest at mid-day, despite the fact that eight hours had elapsed since the morning milking, whereas the evening milking followed at an interval of five hours. Gilchrist suggests that this latter fact may have been due to less care being exercised at the 6 p.m. milking, but in view of the above and other published data precisely similar in nature[2], it is more probable that, where milking is carried out three times daily, the richest milk—in respect of fat—is usually obtained at the noon milking. The data available for solids-not-fat are insufficient to warrant any definite conclusion.

INFLUENCE OF AGE.

Information on this point is afforded by Speir's summary (9) of the results obtained during six months with 903 Ayrshire cows of approximately equal periods of lactation. The following table is abstracted from the one given in the report.

[1] *Trans. Highland & Agr. Soc.* 1903, 140.

[2] *Vide* Ingle, *Trans. Highland & Agr. Soc.* 1901, 223.

From these data it would appear that, in general, taking both yield and quality into account, there is a fairly uniform and steady improvement up to eight years of age, after which there is a gradual falling-off, which probably becomes more pronounced after the twelfth year.

Age of Cow	Number of Cows reported on	Average yield for six months	Average % of Fat in Milk
Years		Galls.	
2	30	362	3·83
3	147	377	3·87
4	164	403	3·76
5	137	421	3·66
6	110	438	3·63
7	88	465	3·63
8	80	468	3·69
9	50	461	3·63
10	36	457	3·64
11	28	464	3·60
12	16	493	3·48
13	10	428	3·42

The effect is more pronounced on the yield than on the fat-content of the milk, the latter showing a deterioration after the third year, which, however, is very slight, the difference between the second and tenth years amounting to no more than ·2 per cent.

There is an obvious risk in basing generalisations on results obtained with different cows in one season, but Speir expresses the opinion that "the number of animals reported on up to eight or nine years old is likely to be sufficient to neutralise the fluctuations which happen in cows of all ages, and the averages obtained may therefore be looked on as approximately correct." A few data in harmony with these generalisations are also given in connexion with the Newton Rigg herd (5)[1].

INFLUENCE OF PERIOD OF LACTATION.

This question is specifically discussed in only one of the reports (1 *b*), and indeed the experiments under review furnish very little reliable information on this important point, since in the great majority of cases they were carried out during the grazing season. It is well known that throughout this period the fluctuation in the quality of the milk yielded by cows is far more pronounced than when the cows are entirely restricted

[1] Very close confirmation is also afforded by the recently published results obtained by Speir during 1904 with 302 cows (*Trans. Highland & Agric. Soc.* 1905, 194).

to the more uniform and more easily regulated conditions of the cow-house. Under grazing conditions, indeed, the normal variations in the quality of milk due to advancing lactation are frequently masked by more pronounced changes arising from causes as yet little investigated. This is especially marked in the case of the percentage of solids-not-fat, which, for example, decreases considerably during a dry summer[1], whereas under normal conditions it would probably tend rather to increase with advancing lactation (see below).

The following table has been compiled, therefore, from those experiments only in which the cows were housed for the whole or the greater portion of the day, and for which the necessary data are available (1 *a*, 3 *a*, 4 *d*, 4 *e*).

Period of Lactation. Month	No. of Cows	Average Fat %	No. of Cows	Average Solids-not-Fat %
I	8	3·78	6	8·95
II	12	3·40	7	8·72
III	10	3·35	5	8·74
IV	6	3·38	4	8·84
V	2	3·56	2	8·81
VI	4	3·86	3	9·03
VII	1	4·05	1	9·00
VIII	5	4·05	5	9·17
IX	4	4·17	4	9·10
X	2	4·27	2	9·29
XI	3	4·70	3	9·49

The number of cows included in the table is by no means large enough to ensure that the averages are not appreciably affected by the differences between individual cows of equal periods of lactation, but so far as they go they confirm clearly the view, now widely accepted, that the quality of the milk is lowest about the second or third month after calving, subsequently improving steadily with advancing lactation[2].

INFLUENCE OF SEASON OF THE YEAR.

This question is touched upon in several of the reports under review.

Thus Ingle in his 1902 report (1 *b*) compared the results obtained by him at Garforth at Easter, 1900, with those obtained there during

[1] *Vide Trans. Highland & Agric. Soc.* 1905, 326.
[2] Confirmed also by Speir, *Trans. H. A. S.* 1905, 197.

August and September of the following year. His averages are as follows:

	Fat %	Solids-not-Fat %
1900 (Mar. 22—Apr. 12)	3·86	9·06
1901 (Aug. 1—20)	3·52	8·70
„ (Aug. 20—Sept. 9)	3·55	8·70

At the same time he pointed out the possibility that the differences in composition may have been due more to differences in the food and condition of the animals than to the actual influence of the season. "It is difficult to eliminate these other influences, and therefore to determine the real character and range of purely seasonal variations."

Dymond and Bull also compared the results obtained in the two experiments carried out by them with 4—5 cows in Essex (3 *a*, *b*), and found but little difference between the mean values obtained during the winter months and those obtained during the summer months, their averages for the winter months (Nov.—Feb.) being 3·70 per cent. fat and 8·92 per cent. solids-not-fat, and for the summer months (May—Sept.) 3·83 per cent. fat and 8·83 per cent. solids-not-fat respectively. The lower percentage of solids-not-fat in the latter case is attributed to an "extraordinary falling-off" in the month of July. From the records of two cows for six months of one and the same lactation they arrived, however, at the conclusion that "during the flush of milk in the spring there is, corresponding to the increase in quantity of milk, a decrease in the proportion of fat and solids-not-fat," and subsequently an improvement in respect of both.

The evidence afforded by the Northumberland experiments (4 *b*, *c*, 5 *a*) is somewhat conflicting, as may be seen from the following data extracted from Gilchrist's report (pp. 57, 58, 61, 69).

Herd	Winter Feeding Indoors (November—April)		Pasture Feeding Outdoors (May—October)	
	Fat %	Solids-not-Fat %	Fat %	Solids-not-Fat %
Broomhaugh	3·85	8·85	3·75	8·57
Seaton Delaval	3·83	8·82	3·82	8·75
Newton Rigg (1903)	4·00	9·07	3·55	8·77

It will be noted that, whereas in the case of the Broomhaugh and Seaton Delaval herds the milk was practically as rich in fat during the summer as during the winter, it was decidedly poorer at Newton Rigg.

Gilchrist suggests that the difference may be ascribed to the fact that the cows at Newton Rigg receive no concentrated food during the first two months on pasture and only a very small quantity subsequently, but in a private communication to the writer Lawrence, of Newton Rigg, asserts that "no improvement either in quantity or quality of milk is found by giving additional food to cows when on grass up to the middle of July." No particulars are given, however, of the experiments on which this assertion is presumably based.

In all cases the percentage of solids-not-fat was decidedly lower during the summer than during the winter months.

In the case of the dairy herd at the Midland Dairy Institute (10), the average percentage of fat for the six months May—October, 1904, was 3·98, and for the remaining six months of the year 4·06—a very slight difference in favour of the winter months.

The evidence obtained in this way is thus conflicting with regard to the percentage of fat, which is obviously considerably influenced by conditions which may vary on different farms.

It may be suggested, however, that the period of six months is too long for the purpose of obtaining satisfactory evidence as to seasonal variations, and that the averages of shorter periods should, where possible, be compared. To this end the following table of monthly averages has been compiled from the available data for the mixed milk yielded in 1903 and 1904 by various herds employed in the experiments under review. For the year 1903 two complete sets of monthly averages (4 *c*, 5) are available, and for eight other herds (1 *d*, 2 *a*; 3 *a*, *b*; 4 *b*, *d*; 6 *b*; 9) the monthly averages have been calculated for periods varying from two to six months from the data given in the reports.

The figures for 1904 are compiled mainly from weekly analyses of the milk of the herd at the Midland Dairy Institute (10), other data (1 *e*, 2 *a*) being available only for the last six months. In every case, in deducing the changes from month to month, the comparison has been restricted to the records of herds for which data are given for the two consecutive months, the number of such herds being indicated in the table by the numbers enclosed in brackets. Thus the data for January and February 1903 are the averages of the records of four herds for which data obtained in these two months are available. Taking then the mean thus arrived at for February (3·65 per cent.) as the standard for this month,

the records of the four herds for which data obtained during February and March are available indicate a standard of 3·85 per cent. for the latter month. The data for subsequent months have then been deduced in similar fashion.

Year	Percentage of Fat											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1903	3·90 (4)	3·65 (4)	3·85 (4)	3·75 (5)	3·65 (3)	3·75 (5)	3·80 (6)	3·75 (4)	3·90 (4)	4·35 (3)	4·40 (3)	4·75 (2)
1904	3·85 (1)	4·10 (1)	4·15 (1)	4·00 (1)	3·75 (1)	3·50 (1)	3·60 (2)	3·60 (2)	3·85 (2)	4·10 (2)	4·30 (2)	4·40 (2)
	Percentage of Solids-not-Fat											
1903	9·05 (4)	9·00 (4)	8·85 (4)	8·85 (4)	8·85 (3)	8·85 (5)	8·70 (5)	8·65 (3)	8·75 (3)	8·80 (2)	8·85 (2)	9·22 (2)
1904	—	—	—	—	—	9·12 (1)	8·99 (1)	8·80 (1)	8·65 (1)	—	—	—

The data for 1903 are probably quite reliable, since the agreement between the individual herds with respect to the direction of the changes is remarkably close.

These data point very clearly to a gradual deterioration in the average fat-content of the milk yielded by these herds during April and May in 1903, followed by a gradual improvement in respect of fat, whereas in the case of the solids not-fat the lowest point was reached in August. Despite the paucity of data available the changes recorded during 1904 are remarkably similar in nature, the minimum percentage of fat being recorded for the month of June and of solids-not-fat for the first half of September, in each case a month later than in the previous year, the differences being probably attributable to the difference in character of the two summers. The falling-off in the percentage of solids-not-fat during the summer of 1904 was freely commented upon at the time, and generally ascribed to the prolonged drought.

It may thus be regarded as fairly probable that the average quality of milk is subject to seasonal variations, particularly during the pasturage season, the fat-content reaching its minimum generally in the months of May or June, whilst the deterioration in respect of solids-not-fat is more

prolonged, the lowest point being reached probably as a rule in July, August, or September, according to the nature of the season.

INFLUENCE OF FOOD.

Great differences of opinion with regard to this important question still exist among practical agriculturists, and hence it has received a considerable share of attention in the reports under review, many of the experiments (1 *b*, *d*, *e*, 2 *b*, 6 *a*, 7, 11) indeed having been specifically designed to ascertain definitely the nature and magnitude of this influence.

The Garforth experiments (1 *b*, *d*, *e*) are the most extensive, including as they do three distinct series of investigations carried out in different years during the months of June, July, and August, throughout which the cows were at pasture day and night. In each of the three investigations the effect of a change in the nature and albuminoid ratio of the dry food given to supplement the pasturage has been studied by comparing the average yield and quality of the milk obtained from a small group of cows during a period immediately *prior* to the change with the average yield and quality of the milk obtained from the same cows during a definite period immediately *subsequent* to the change. In order to eliminate as far as possible any disturbing effects, the data obtained with the cows under experiment have in each case been compared with those obtained with a similar group of cows (carefully selected to resemble the test-group as closely as possible), which received the same diet throughout the whole experiment. Throughout the investigations the milk of each individual cow was sampled at each milking.

In the experiment carried out in 1901 (1 *b*) the 19 cows included were fed uniformly for several weeks prior to and throughout the first 20 days of the experiment (Control Period), each receiving as dry food 2 lbs. decorticated cotton cake daily. After the twentieth day the cows were divided into four groups, one group (the control group) continuing to receive the same food, a second receiving daily 4 lbs. of gluten meal, a third 6 lbs. of maize meal, and the fourth 28 lbs. of fresh brewers' grains, instead of the decorticated cotton cake. The experiment was continued for 20 days after the change of food (Test Period).

The following table, modified from the original, gives the averages for the second period for each group, recalculated on the assumption

that in the first period each had given mean results identical in every respect with those of the control group.

	No. of Cows	Yield, lbs.	Fat %	Solids-not-Fat %
Control Period (20 days), (all groups)		114·4	3·38	8·55
Test Period (20 days):				
Cotton Cake (Control Cows)......	5	103·6	3·48	8·59
Gluten Meal..........................	5	107·9	3·52	8·67
Maize Meal	5	107·0	3·30	8·56
Brewers' Grains	4	100·7	3·46	8·55

From these figures it is obvious that the changes produced were small in every case, and possibly the differences indicated were within the limits of experimental error. In this connexion Ingle remarks that "it must be remembered that the figures are deduced from the differences between the means of two sets of analyses, each set containing 40 independent values for the milk of each cow. That the changes were in the direction indicated, therefore, I think we may feel tolerably certain, but any conclusions that we draw from this investigation as to the influence of food must be applied only to similar cases."

Assuming the figures to be reliable to the extent suggested, it would appear that the best results were yielded by the gluten meal—a typical highly nitrogenous food—and the worst, so far as the quality of the milk is concerned, by the maize, a food relatively poor in albuminoids. The data referring to brewers' grains are not of special interest, since "the feeding of grains to cows at pasture is an unusual practice." Attention may simply be directed to the fact that, "contrary to what was expected," this group of cows showed relatively the greatest *diminution* in yield.

"Another important question upon which this investigation fails to throw any light is, whether the changes in milk produced by change of food are only temporary or last for any appreciable time. It seems highly probable that the mere fact of changing the food may stimulate the vital processes of the animals and so alter their milk, but that, when this stimulus has disappeared, the old order of things may be restored and the milk may return to its normal condition." (Ingle.)

In view of this uncertainty and the great importance of the question, further experiments on similar lines were carried out at Garforth by the

writer in the summers of 1903 and 1904 (1 *d*, *e*). In the former year the effects of a replacement of 2 lbs. decorticated cotton-seed meal and 1 lb. wheat meal by 3 lbs. of maize meal was studied with a group of five cows for five weeks after the change of food, in order to test more thoroughly the degree of permanency of any changes recorded.

In the latter year the effects of change of food were studied with a group of seven cows, but for 19 days only, in connexion with a more extensive investigation. In this year the change of food investigated consisted in the replacement of 3 lbs. decorticated cotton cake by 3 lbs. maize meal.

The cows were at pasture day and night throughout each experiment, and the method of procedure was precisely that of the 1901 experiments outlined above.

The results are summarised in the following table, drawn up in precisely similar fashion to the preceding one (p. 162).

	No. of Cows	Mean Daily Yield, lbs.	Fat %	Solids-not-Fat %
1903				
Control Period (17 days), (all Cows)...		108·0	3·27	8·74
Test Period (52 days):				
First 3 weeks—				
Cotton-seed Meal (Control Cows)	5	91·5	3·40	8·50
Maize Meal..............................	5	98·8	3·31	8·49
Last 2 weeks—				
Cotton-seed Meal (Control Cows)	...	79·5	3·60	8·52
Maize Meal..............................	...	87·7	3·41	8·62
1904				
Control Period (28 days), (all Cows)...		213·6	3·36	8·88
Test Period (19 days):				
Decort. Cotton Cake (Control Cows)	7	190·6	3·50	8·82
Maize Meal	7	185·9	3·41	8·74

So far as the quality of the milk is concerned, it will be noted that the results closely confirm those obtained in the previous experiment, in that slightly richer milk was obtained with the more nitrogenous food, the only exception being in the case of the solids-not-fat for the last two weeks of the test period in the 1903 experiment. From the respective data given for the first three and last two weeks of the test period in this experiment it would appear as if the influence of the change of food had remained unabated throughout the whole period, but in the 1904

experiment the changes produced were apparently far more temporary in character, as is evident from the weekly averages given in the report[1]. The experiments are thus indecisive with regard to this point.

The fact must not be overlooked that there is considerable possibility of error in the assumption underlying these methods of investigation that any deviations in the case of the test group from the magnitude and direction of the fluctuations recorded by the control group are to be attributed to the changes investigated. This possibility is of course less the greater the number of cows experimented with, and in this connexion it is perhaps significant that the smallest effects were recorded in the series of experiments with the largest groups, viz., in 1904.

It must further be admitted that the conditions at Garforth are in some respects ill adapted for experiments of this nature, the marked inequality of the intervals between milkings conducing to greater fluctuations in the quality of the milk, and consequently a higher probable error of the mean results than would be the case if milking were carried out at equal intervals.

The close agreement between the results obtained in different years is, however, presumptive evidence that the experiments were at least precise enough to indicate the direction, if not the magnitude, of the changes effected.

An experiment on similar lines (7) was also carried out with six cows by Atkinson at Wye in the last three months of 1901, with the object of comparing the effect of additions of a highly nitrogenous food —linseed cake—and a typically starchy food—maize meal—respectively to a ration of average albuminoid-content but rather low in quantity. The experiment was continued for two months after the change of ration, and the conclusion arrived at as to the effects of the changes investigated was that, "taking the results generally, it appears that neither the change from a low diet in point of quantity to a higher one, nor the change from a medium diet in respect of albuminoids to a more or less nitrogenous one, affected the amount of butter-fat given to any appreciable extent....As far as these experiments go, they tend to support the view that the amount of butter-fat a cow gives is not materially dependent upon the nature of her food, but is governed by other causes, such as the period of lactation, and each cow's peculiar aptitude to produce richer or poorer milk." Possibly if a larger number of cows could have been employed for the experiment, slight differences such as those observed at Garforth might have been detected.

[1] *Highland & Agric. Soc. Trans.* 1905, 331, 332.

Similar conclusions were arrived at in the experiments carried out in connexion with Reading College in Jan.—March, 1902 (6 *a*), in which three different rations were tested with three lots of four cows each, and also in the comparison of the feeding value of different varieties of mangels carried out with eight cows in 1903 (6 *b*).

In the experiment carried out at the Harper Adams College in 1904 (2 *b*), decorticated cotton cake (6 lbs.) and maize (8 lbs.) in quantities representing equal money values were compared with two lots of three cows each. The results indicated a slight advantage in favour of the cotton cake in respect both of yield and quality.

In Robb's experiments (11), in which four groups of six cows each were employed, the feeding value of gluten feed was compared with that of a mixture of bean meal and crushed oats on the one hand, and a mixture of maize meal and decorticated cotton cake meal on the other hand. A further comparison was also effected of the relative feeding values of equal weights of sugar beets and turnips. Although there were in some cases marked differences in the effects of the different rations on the yield of milk—notably the relative inferiority of the ration comprising maize and cotton cake meal—the proportion of fat and solids-not-fat in the milk was apparently in no case appreciably affected.

The influence of food on the milk-secretion has also been touched upon in the reports of other experiments not specially designed for the investigation of this point (3 *a*, 4 *d*), and in each case the opinion has been formed that changes of food have little if any effect on the milk.

These experiments—carried out under summer and winter conditions, in widely different parts of the country—are thus unanimous in indicating that such changes as may possibly be effected in the quantitative composition of milk by change of food are only very slight, provided, of course, the rations prior and subsequent to the change are suitable in nature and in quantity.

Very few observations have apparently been made in the course of these experiments as to the influence of food on the *qualitative* composition of milk, although there is every reason to believe that the effects are most pronounced in this respect. Thus Robb reports decided differences in the churnability of the cream and on the flavour and quality of the butter produced from the milk of cows receiving different foods.

INFLUENCE OF MANNER OF FEEDING.

Experiments have been carried out at Garforth in the years 1902-4 (1 *c*, *d*, *e*) with the object of investigating the possibility of periodically stimulating the production of fat by feeding cows at stated times with rich food, given to supplement pasturage.

The method of investigation adopted (Ingle, 1902)—after an unsuccessful attempt to ascertain the interval between feeding and its effect upon the milk by the admixture of colouring matters with the food—consisted in comparing the records of three groups of four cows each for a period of five weeks, one group (control cows) receiving its dry food in two equal portions, morning and night—the customary manner of feeding at Garforth, and adopted with all the cows during the immediately preceding (control) period—a second receiving its dry food in the morning only, and the third receiving its dry food at night; the total weight of food supplied per day being the same in each case.

The experiments were repeated by the writer in 1903 and 1904 on precisely similar lines, save that in the latter year the effect of exclusively evening feeding was not investigated.

The results of the three series of experiments are summarised in the following table (p. 167), containing data modified somewhat from those given in the original reports in that, to facilitate comparison, the assumption has been made that the average fat-content during the period of normal feeding (dry food given in two equal portions) was 3 per cent. in each case, and the data obtained in other periods correspondingly modified, due attention being paid to the normal fluctuations as measured by the control group.

If this method of analysing the experimental data may be trusted there would appear to have been a decided difference in favour of the more intermittent mode of feeding. It may be noted, however, that the apparent effect was far less pronounced in the two latter years than in 1902, and moreover that, whether the food was given all in the morning or all at night, the apparent effects were not confined to the one or the other milking. The ratio between the percentages of fat in the morning and evening milk respectively was indeed narrowed somewhat by the more intermittent feeding in some of the experiments—notably in the 1902 experiments—but not in all.

Here again, as in the investigations into the influence of change of food (*vide* p. 164), it is significant to note that the least effects were recorded in the experiment in which the groups were largest.

Year of Experiment	No. of Cows in Group	Morning Milk			Evening Milk		
		Dry Food given			Dry Food given		
		In two equal portions	All in Morning	All at Night	In two equal portions	All in Morning	All at night
		%	%	%	%	%	%
1902	4	3·00	3·53	3·41	3·00	3·28	3·27
1903	4	3·00	3·12	3·17	3·00	3·14	2·97
1904*	7	3·00	3·05	—	3·00	2·95	—
Mean...	....	3·00	3·21	3·03	3·00	3·11	3·12

* The 1904 experiment was but part of a more comprehensive experiment in which the writer endeavoured to determine the effect on the milk of a group of 7 cows of a simultaneous change in the nature of the stall food and the mode of feeding—full details of which are given in the report (*Highland and Agr. Soc. Trans.* 1905). No very definite effect could be detected beyond the slight disturbance immediately subsequent to the sudden introduction of the changes, this being, so long as it lasted, precisely similar in nature to the changes observed under similar conditions in previous years.

Further investigation of the question is desirable, but from these experiments it appears not improbable that some change, perhaps only very slight, may be effected in the quality of milk by changes in the manner of feeding such as those referred to above.

INFLUENCE OF WEATHER.

Apparently very little reliable evidence is available with respect to the influence on the milk-secretion of fluctuations of temperature and weather conditions generally to which cows are subjected.

The problem is touched upon and to some extent discussed in some of the reports under review, but in no case has it been really satisfactorily dealt with.

It is not to be wondered at, therefore, that diametrically opposite conclusions have been arrived at by different investigators. Thus Dymond and Bull (3*a*) report that "the temperature out of doors has had extraordinarily little effect on either milk-yield or quality.... The only marked change was observed when the temperature of the cowhouse fell below 50°," which caused a falling-off in yield, "but it did not appreciably affect the percentage of fat or solids." A similar conclusion is again arrived at in the recently issued report of the

committee (Messrs Dyer, Dymond and Thresh) appointed by the Essex County Council to investigate this question. This report is based on a careful comparison, month by month, of the rainfall records with the average quality of milk in Essex during each month of the past three years, as indicated by the results of analyses of nearly 1200 samples taken within the county under the Sale of Food and Drugs Act. Similarly, Ingle in his first report (1 *a*) states that no distinct influence of change of temperature (of the cowhouse) upon the composition of the milk could be traced.

On the other hand, Gilchrist, in his summary of the results of the experiments carried out under his direction in Northumberland (4 *b*–*f*), remarks that "the weather conditions have evidently a very important influence on milk production. This is especially noticeable in the Seaton Delaval results, where cold north and north-east winds have considerably lowered the fat-contents of the milk. The milk of one cow at Cockle Park has been reduced in percentage of fat by cold nights in June and by hot days in July. Wilson has also found at Stockton-on-Tees that severe weather has reduced the amount of fat. It is therefore advisable to guard against exposing cows unduly to either severe or hot weather, and especially to great variations in temperature."

Again, Ingle in his second paper (1 *b*) instances one "cool, dull day following several exceedingly hot ones," on which "the separate (evening) milk of almost all the cows was of unusually high quality." This phenomenon was also noted several times by the writer during his investigations in 1903.

Atkinson, in his report on the feeding experiment carried out by him at Wye (7), suggests that the "very marked drop" in the fat-content of the milk of each cow during the third week of the experiment was probably due to the "very raw, foggy weather" that prevailed.

It should be noted, however, that in most cases where an attempt has been made to arrive at the influence, if any, of variations of weather on the milk-secretion, the attention has been mainly concentrated on the fluctuations in quantity and quality of the *mixed milk* of herds. It is doubtful whether much reliable information may be obtained in this way. The effect, if any, will be exerted on the milk-secretion through the nervous organisation of the cow, and it is well known that there are very great differences in nervous temperament between individual cows. It is practically certain, therefore, that the magnitude of the effects produced on the milk-secretion by changes of weather will vary considerably with different cows, and it is quite possible that there may even be

differences in the nature of the changes in the case of different cows. More reliable information may therefore be expected from a comparison of the meteorological data with the records of individual cows, and particularly such as are notably of highly nervous temperament.

An attempt was made by the writer, in connexion with the experiments carried out at Garforth in 1903, to effect roughly such a comparison, the results of which are fully discussed in the report (1*d*). A table was constructed, recording for each of the 52 days on which samples were taken the respective numbers of cows giving milk either decidedly above or below the average for the particular period of the experiment in which each day occurred, and the data thus obtained were compared with the daily fluctuations in the general weather conditions. From this comparison a far greater degree of regularity between the climatic changes and the fluctuations in the quality of the milk yielded by the cows was traceable than could be seen from the data for the mixed milk. The connexion was still, however, not sufficiently exactly defined to admit of absolutely trustworthy conclusions being arrived at, but certain opinions were expressed which received considerable support from the experimental data. These opinions were to the effect that, with most of the cows during pasturage,

(*a*) Change from an equable to either a decidedly low or a decidedly high temperature tended at first to produce a secretion of milk poorer in fat.

(*b*) The first effect of a fall of rain would appear to have been to cause secretion of richer milk, this being especially noticeable in the morning milk after wet nights[1].

(*c*) The influences were only of a very temporary nature, the return to normal conditions being fairly rapid with a continuance of fairly uniform climatic conditions.

These opinions were given, however, with all reserve, being based on observations extending over a very limited period. It is hoped that more reliable information will accrue from the further comparison of the analytical data accumulated at Garforth with the more precise expression of the climatic changes afforded by the meteorological records.

[1] It is possible of course that the effects ascribed to the weather conditions may in many cases arise only indirectly therefrom. Thus rain after drought will considerably affect the succulence of the herbage and may thereby produce an effect on the milk-secretion.

Comparison of Night Pasturage with Housing of Milking Cows in Autumn.

This important practical question has been the subject of experiment during the last four winters at the Harper-Adams Agricultural College.

In each year 10 cows have been selected, carefully arranged in two equal groups, and treated exactly alike except that, whereas one group remained at pasture day and night, the other group were housed from the evening milking of one day to the close of the following morning milking, receiving a quantity of hay in the racks to compensate for the removal from pasture. The experiments covered the months of October to December, and the comparison of the two systems was based on analyses of composite samples of the morning and evening milk taken frequently before and after the commencement of the experiment.

The results are striking, being quite contrary to general opinion in that they reveal no advantage accruing from the night housing, neither in respect of yield nor quality of the milk, but rather the reverse. In nearly every case the milk yield fell off less rapidly and the fat-content of the milk increased more rapidly in the case of the cows which remained at pasture through the night than in the case of the cows passing the night in the cowhouse. Moreover the former invariably showed a greater increase in live weight than the latter, indicating that, to say the least, they did not suffer by the treatment.

This result is so remarkable and contrary to general expectation, and of such practical importance, that independent confirmation is highly desirable.

A certain degree of confirmation is afforded by a small experiment carried out on similar lines—in ignorance of the Harper-Adams experiments—by the writer at Garforth during the last few days of August and the first half of September, 1904. Four cows, which for several months previously had been at pasture day and night, were housed at night during this period, receiving hay *ad lib.* in the stalls. Their records have been compared with those of a similar group of cows which were at pasture day and night, and have proved to be practically identical. It may be objected that the period at which this experiment was carried out was unduly early, and indeed it was intended to be only preliminary to a more thorough investigation. Still if there be, in general, any marked difference in the effects of the two modes of treatment of the cows, surely this would have been evident to some extent in the results.

INFLUENCE OF SEXUAL EXCITEMENT.

This question is referred to in several of the reports (1 *b*, *d*, 3 *b*, 4 *e*, *f*), the data accumulated affording many instances of remarkable fluctuations in the amount and quality of the milk yielded by cows when under this influence.

In every case it is noted that the magnitude of the influence varies enormously with different cows, being indeed in many cases quite inappreciable. Moreover, even in those cases where the milk-secretion is undoubtedly affected, there is apparently no absolute regularity in the effects produced, nor in the period throughout which the effects are evident.

In most cases the milk obtained at the first milking after the outward manifestation of sexual excitement is abnormally low in quantity and poor in fat—the proportion of solids-not-fat remaining practically unaffected, whilst at the following milking an unusually high yield of milk rich in fat is generally recorded. These fluctuations in some of the recorded cases amount to as much as 300 or 400 per cent. of the lower values.

Numerous instances of such fluctuations were recorded by the writer in 1903 (1 *d*) in connexion with the cows of the Garforth herd. From the comparison of these data the opinion was expressed that the influence is inappreciable after two or three milkings subsequent to the cow coming in "season."

Attention was also directed to the fact—noted also in the report of the Northumberland experiments (4)—that in many cases the fat-content of the milk was decidedly above the average on the two or three days immediately preceding the period of active sexual excitement.

COMPOSITION OF MILK FROM SEPARATE PORTIONS OF THE UDDER.

An interesting series of analyses of the milk drawn from each separate quarter of the udders of several cows was published by Ingle in his report on investigations carried out by him in the summer of 1902 (1 *c*).

Samples were taken twice daily for six days from two cows, and on analysis revealed very striking differences in composition, especially in respect of solids-not-fat. In the case of both animals the lowest proportion of solids-not-fat was invariably found in the milk from the same quarter—the left fore teat—and in every case the quantity of milk

yielded by this quarter was much less than that from the other quarters of the same cow.

In order to test the generality of this phenomenon a set of four samples was taken from each of the 19 cows in the herd. Of these, 10 gave distinct indications that the left fore-quarter gave milk less in quantity and poorer in solids-not-fat than any of the other three quarters, the means for these 10 animals being:

	Fat %	Solids-not-Fat %	Milk Yield, lbs.
Right fore-quarter	3·93	8·71	2·73
Right hind-quarter......	4·24	8·70	3·25
Left fore-quarter.........	3·87	8·18	1·83
Left hind-quarter	4·02	8·70	2·82

Of the remaining nine animals, three yielded milk poorest in solids-not-fat from the right hind-quarter, whilst the other six cows gave results which were not conclusive.

These differences were apparently, however, not permanently characteristic, for when after an interval of four or five weeks further samples were drawn from one of the two cows whose milk was first sampled, it was found that the left *hind*-quarter was now the one giving milk poorest in solids-not-fat, and this was still the case some nine or ten weeks later. With these later samples direct determinations of albuminoids and sugar were made, and it was found that the poverty in solids-not-fat of the milk from the left hind-quarter was attributable to the low proportion of sugar.

Ingle, in conclusion, remarks that "the variation in fat in milk from different quarters of the udder is perhaps not surprising when we remember that the fat is apparently produced by the breaking-down of fat-cells in the gland itself; but that different glands, or different parts of the same gland, should be able to elaborate from the same blood supply products of different concentration in dissolved matter, appears to the writer to be very remarkable."

Average Composition of Milk.

The investigations under review comprise in all about 50 different herds ranging in size from 3 to 61 cows, and located in widely different parts of the country. They furnish therefore a considerable

amount of evidence concerning the average quality of milk as obtained in this country, and it is of interest to compare the different records.

The following table has therefore been drawn up from the data, relative to the mixed milk of the herds, furnished by each report; such data being in many cases based on analyses of actual samples of the mixed milk, and in others arrived at by calculation from the results of analyses of the samples of the milk of each individual cow.

Experiment	No. of Herds	Average No. of Cows per Herd (approx.)	Morning			Evening			All Samples		
			No. of Samples (approximate)	Fat %	Solids-not-Fat %	No. of Samples (approximate)	Fat %	Solids-not-Fat %	No. of Samples (approximate)	Fat %	Solids-not-Fat %
1	1	18	366	2·91	8·90	364	4·20	8·84	730	3·56	8·87
2	1	8	—	—	—	—	—	—	75	3·81	—
3	1	5	173	3·62	8·84	173	3·84	8·93	346	3·73	8·89
4	5	11	162	3·48	8·80	162	4·13	8·65	324	3·81	8·73
5	1	17	12	3·63	9·00	12	3·83	8·84	24	3·73	8·92
6	2	10	45	2·89	—	45	3·71	—	90	3·30	—
7	1	6	—	—	—	—	—	—	120	3·25	—
8	1	3	28	2·99	8·89	28	3·96	8·92	56	3·48	8·90
9	19*	40	190	3·77	—	190	3·85	—	380	3·81	—
	34*	39	—	—	—	—	—	—	450	3·68	—
10	1	28	33	3·49	—	33	4·08	—	66	3·79	—
11	1	24	70	3·16	8·47	70	3·42	8·47	140	3·28	8·47
Total	49	—	1080	3·60†		1080	3·90†		2800	3·70†	
			710		8·81†	710		8·74†	1420		8·78†

* In the case of nineteen of the thirty-four heads tested in this experiment, samples of the mixed milk at each milking were tested in addition to samples from each individual cow.

† Average per herd.

It will be observed that the averages deduced from all samples agree very closely with the well-known averages of the Aylesbury Dairy Company, which are so commonly accepted as representative of the average quality of milk as supplied in this country.

The quality of individual samples frequently deviated considerably from these means, however, as may be seen from the following table, in which are given the extreme limits of variation recorded in the case of the mixed milk of each herd (of five or more cows) for which data are available.

LIMITS OF VARIATION IN QUALITY OF MIXED MILK OF HERDS.

Experiment	Fat		Solids-not-Fat	
	Minimum °/o	Maximum °/o	Minimum °/o	Maximum °/o
1 *a*	2·9	5·0	8·6	9·5
1 *b*	2·0	4·8	—	—
1 *c*	2·2	5·3	8·6	9·2
1 *d*	2·55	5·25	8·4	9·4
1 *e*	2·55	5·1	8·45	9·35
3 *a*	3·04	4·36	8·6	9·45
3 *b*	3·12	4·87	8·6	9·3
4 *b*	3·03	4·53	8·75	9·45
4 *c*	2·8	4·6	8·4	9·3
4 *d*	3·3	4·6	8·55	8·9
5............	3·0	4·4	8·55	9·35
6 *a*	3·25	4·05	—	—
10..............	3·0	4·7	—	—
All Experiments ...	2·0	5·3	8·4	9·5

The range of variations is, of course, still greater in the case of samples drawn from the milk of individual cows, but in no case are values recorded outside the limits—Fat 1·04—12·52 per cent.; Solids-not-Fat 4·90—10·60 per cent.—quoted by Richmond[1].

In conclusion, the writer would take this further opportunity of expressing his indebtedness to the various investigators whose work has been touched upon in this *résumé*, for generous responses to requests for more detailed information in connection with their experiments.

[1] *Dairy Chemistry*, p. 120.

No.	Investigations in connexion with	Year	Commenced	Period covered Investigation	Number of C	Ratio of Inter between Milki Day Interva Night Inter	Frequency of Sampling	Details of Publication of Results
				Days				
1 a	University of Leeds (Garforth Experimental Farm)	1900	22. iii.	21	17	1 : 1·6	Twice daily	Ingle, *Highland & Agric. Soc. Trans.* 1901, XIII. 218
				4	4	: 1 : 1 : 1	4 times ,,	
1 b	,, ,, ,, ,, ,, ...	1901	1. viii.	40	19	1·6	Twice daily	,, ,, ,, ,, 1902, XIV. 284
1 c	,, ,, ,, ,, ,, ...	1902	25. v.	63	17	,,	,, ,,	,, ,, ,, ,, 1903, XV. 135
1 d	,, ,, ,, ,, ,, ...	1903	10. vi.	52	18	,,	,, ,,	Crowther, ,, ,, ,, 1904, XVI. 268
1 e	,, ,, ,, ,, ,, ...	1904	7. vi.	95	14	,,	,, ,,	,, ,, ,, ,, 1905, XVII. 296
2 a	Harper-Adams Agricultural College	1901	2. xi.	35	10	1·5	1 day weekly	*Report for Season* 1904, p. 13
		1902	22. xi.	21	,,	,,	,, ,,	
		1903	31. x.	28	,,	,,	,, ,,	
		1904	5. xi.	56	,,	,,	,, ,,	
2 b	,, ,, ,, ,,	1904	—	42	6	—	—	Private communication from Mr Foulkes
3 a	Essex Education Committee	1902	18. xi.	103	4	1·1	Twice daily	Dymond and Bull, *Special Pamphlet*
3 b	,, ,, ,,	1903	11. v.	140	4—5	,,	Twice daily for five separate fortnights	,, ,, ,, ,,
4 a	Armstrong College, Newcastle-on-Tyne	1902	1. x.	—	18	2·4	Twice daily	Collins, *Journ. Soc. Chem. Ind.* 1902, XXI. 1512
4 b	,, ,, ,, (Offerton Herd)	1903	10. i.	71	12	1·6 : 2·2	1 day fortnightly	*Twelfth Annual Report on Experiments*, 1903, 54 (Durham College of Science)
4 c	,, ,, ,, (Broomhaugh Herd)	,,	14. i.	336	12	1·3	,,	,, ,, ,, ,, ,, 57
4 d	,, ,, ,, (Seaton Delaval Herd)	,,	4. iii.	40	6	1·3	Twice daily	,, ,, ,, ,, ,, 59
4 e	,, ,, ,, (Alnwick Herd)	,,	19. iii.	33	3	1	,, ,,	,, ,, ,, ,, ,, 64
4 f	,, ,, ,, (Cockle Park)	,,	1. i.	113	1	1·2–2	,, ,,	,, ,, ,, ,, ,, 67
			19. v.	165	1	1·1–2	,, ,,	,, ,, ,, ,, ,, 68
5	Cumberland and Westmoreland Farm School (Newton Rigg)	,,	15. xii. '02	335	17	1·1	1 day monthly	,, ,, ,, ,, ,, 69
6 a	University College, Reading	1902	5. i.	84	12	—	,, ,,	Percival, *Journ. Board of Agric.* 1903, IX. 51
6 b	,, ,, ,,	1903	10. iii.	42	8	1·7	Twice daily	,, *Ninth Annual Report on Experiments*, 1903, 5
7	South-Eastern Agricultural College, Wye	1901	20. x.	64	6	1·4	,, ,,	Atkinson, *Journ. S.-E. Agric. College*, No. 11, Feb. 1902
8	Cambridge University	1903	12. v.	28	3	1, 2	,, ,,	Rudge, *Fifth Annual Report on Experiments*, 1903, p. 92
9	Highland and Agricultural Society	,,	11. v.	180	1342	1	1 day fortnightly	Speir, *Highland & Agric. Soc. Trans.*, 1904, XVI. 170
10	Midland Dairy Institute	1904	1. i.	365	26	1·3	1 day weekly	Private communication from Mr Golding
11	West of Scotland Agricultural College	1903	11. ii.	70	24	1·1	Twice daily	D. K. Robb, *West of Scotland Agric. Coll. Bull.*, No. 29

VARIATION IN THE CHEMICAL COMPOSITION OF MANGELS.

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THE investigations described in the following pages are the outcome of a series of experiments started in the spring of 1902, on the University Farm, and on three farms in the county of Norfolk. The Norfolk Chamber of Agriculture, after investigating the manuring of root crops in 1886 and succeeding years[1], and the utilisation of root crops for feeding sheep and cattle during the nineties[2], turned its attention in 1900 to the investigation of the quality of the root crop. During 1900 and 1901 a feeding experiment was carried out with swedes grown with various manures, and both the analyses of the roots and their effect on the cattle[3] showed that the feeding value of the roots was affected by manuring to an almost inappreciable extent. It was therefore proposed to the Chamber that, before any further feeding experiments (which are lengthy, costly, and extremely difficult to carry out satisfactorily) were organised, an extended investigation in the field and in the laboratory should be carried out, in order to determine the extent of variation in quality of which root crops were susceptible. The experiments were therefore started on the University Farm in the spring of 1902, with the co-operation of the Chamber, who arranged to grow material on three farms in Norfolk, and have been continued in the two succeeding seasons. They have been extended since the first year by the co-operation of the Bedford County Institute at Ridgmont, which grew material in 1903 and

[1] *Annual Reports of the Norfolk Chamber of Agriculture.*
[2] *Ibid.*, and *Journal of the Board of Agriculture*, 1899, VI. p. 311.
[3] *4th Annual Report Camb. Univ. Dept. of Agric.* 1901–2, p. 73.

1904, and of the County Councils of Essex and West Suffolk in 1904. Short preliminary notes on the progress of the work have already been published[1], and now, after three years' work, and the examination of 600 large mixed samples and over 1000 individual roots, we are in a position to state certain definite conclusions with regard to mangels. A large amount of work has also been done on swedes, turnips, and kohl rabi, but the results are not at present sufficiently definite for publication.

But little information as to the variation in the composition of roots can be found in modern standard works on agricultural chemistry. Wolff[2] gives 12 per cent. as the average content of dry matter in mangels, and makes no suggestion as to variability; Warington[3] states that small roots (mangels) contain on the average 13 per cent., and large roots only 11 per cent. of dry matter; and Stephens[4] gives 12·2 per cent. as the average content of dry matter, but adds that it may vary from as little as 10 per cent. in wet seasons to as much as 16 per cent. in dry seasons, and he too notes that small and medium-sized roots contain more dry matter than large ones.

That very considerable variation does occur beyond that due to soil and season is seen at once on consulting periodical literature. A. Voelcker[5] gives analyses of nine single roots of the Orange Globe mangel, each from a differently manured plot, in which variations are shown in dry matter from 7·4 to 10·5 per cent., in sugar from 2·3 to 5·6 per cent., and in nitrogen from ·17 to ·26 per cent.

Anderson's[6] analyses of three varieties show very considerable variation in composition. Thus the percentage of dry matter varies from 9·44 in Long Red and 9·76 in Yellow Globe to 11·57 in Long Yellow. He also points out that care in sampling roots is necessary, as the composition varies in different parts of the root.

A later paper[7] by the same author, this time on swedes, is of considerable interest. It gives in parallel columns analyses of 20 individual roots, their specific gravity, and the specific gravity of their juice. The analyses were made to test the soundness of a method of selection practised at that time by the then Marquis of Tweeddale, which

[1] *Proc. Camb. Phil. Soc.* 1903, xii. 2. 97; *5th Annual Report Camb. Univ. Dept. of Agr.* 1903; *Report of Brit. Assoc. Agric. Sub-Sec.* 1904.

[2] "Farm Foods," *Cousins' Trans.* p. 306.

[3] *Chemistry of the Farm*, 1902 ed., p. 130.

[4] *Book of the Farm*, 4th ed. i. 265.

[5] *R.A.S.E. Journal* 1866, ii. 2. p. 201.

[6] *Highland Soc. Trans.* 1853–5, p. 274.

[7] *Highland Soc. Trans.* 1855–7, p. 183.

consisted in growing on for seed the roots of highest specific gravity. Anderson's figures show that very great variation occurs in the composition of the individual roots, and in the specific gravity of both root and juice, but that the specific gravity of the root indicates rather the amount of included air than the composition of the root. He considers that the specific gravity of the juice is a surer indication of high percentage of dry matter, but his figures do not seem to bear out this conclusion. Cp. p. 206.

Wilson[1] quotes figures showing that considerable variation occurs between different varieties, Long Red containing only 1·60 per cent. of nitrogenous compounds, as against 2·12 per cent. in Red Globe.

Many analyses of mangels have been made on the Continent and in America[2]; these show great variation in composition, but we have not been able to find the data as to variety, season, manurial treatment, and cultural conditions, to enable us to decide as to the causes of variation.

The Rothamsted figures[3] show seasonal variation in mangels grown without manure from 12·18 per cent. dry matter in 1895, to 18·94 per cent. in 1887, and a difference of 3·2 per cent. on the average of 25 years between mangels grown without manure and with complete artificials.

It is evident therefore, from perusal of the literature quoted above, that mangels are subject to great variation in chemical composition, and that this variation is due to a number of causes, among which may be mentioned individuality, size of root, strain, season, and manuring.

METHOD OF EXPERIMENTING.

The method adopted in carrying out the investigation has been to sow annually at several stations a number of seedsmen's strains of swedes, mangels, and turnips. These were sown on plots side by side, and treated similarly in every possible way, both culturally and manurially. In the autumn the crop of each plot was weighed if possible, sampled, and analysed.

Comparison of the figures gives information as to the variation among the different strains on different soils, and comparison of the figures for the three years gives some idea of seasonal variation.

[1] *Our Farm Crops*, I. p. 450, Edinburgh, 1859.

[2] *Jahresbericht über Agric. Chemie*, 1880 to 1890.

[3] *Annual Memoranda*, 1901.

Other plots were grown with the same strain differently manured, analyses of samples of which gave information as to the variation caused by manuring.

Large numbers of individual roots of several strains were weighed, sampled, and analysed, to obtain information as to variation with size and individuality.

Anderson's work, quoted above, calls attention to the uneven distribution of certain constituents throughout the root. This question has been more fully investigated, and information obtained as to the distribution of dry matter, sugar, and nitrogen through the root, and a method of sampling devised to meet the case.

SAMPLING.

In deciding on a method of sampling a crop of roots, two points have to be taken into consideration, firstly how to obtain a small portion which shall fairly represent the composition of one individual root, and secondly how many individual roots must be so sampled in order to obtain a representative sample of the whole crop.

For sampling individual roots two methods have been used. One of them consists simply in cutting out a vertical sector from the root, and reducing this to pulp by some kind of rasp. This method necessitates the manipulation of large quantities of material, and is therefore cumbrous where large numbers of samples have to be collected from considerable distances. We therefore inclined to the other method, which is essentially the removal from the root of a core by means of an instrument like a cheese-borer. Such cores are rapidly taken, and pack easily for carriage to a distance.

Removal of a core does not damage the root for seed-growing; in fact, coring is the method adopted for sampling sugar-beet for the chemical selection of roots for seed-mothers, and has been used with such marked success that the method may be taken as reliable. It has also been used by Collins[1] in his work on swedes.

During our first year's work we tested the method carefully by determining the percentages of dry matter in 100 individual roots, each of which was first cored and then divided into vertical sectors. The core was dried to constant weight, and side by side with it one of the sectors representing as nearly as possible one quarter of the root. The

[1] *10th Annual Report Durham College of Science*, 1901.

means of the two series of determinations differed by less than ·1 per cent., thus:

Mean of 100 determinations by the coring method, 12·81 per cent.
" " " " sector " 12·76 "

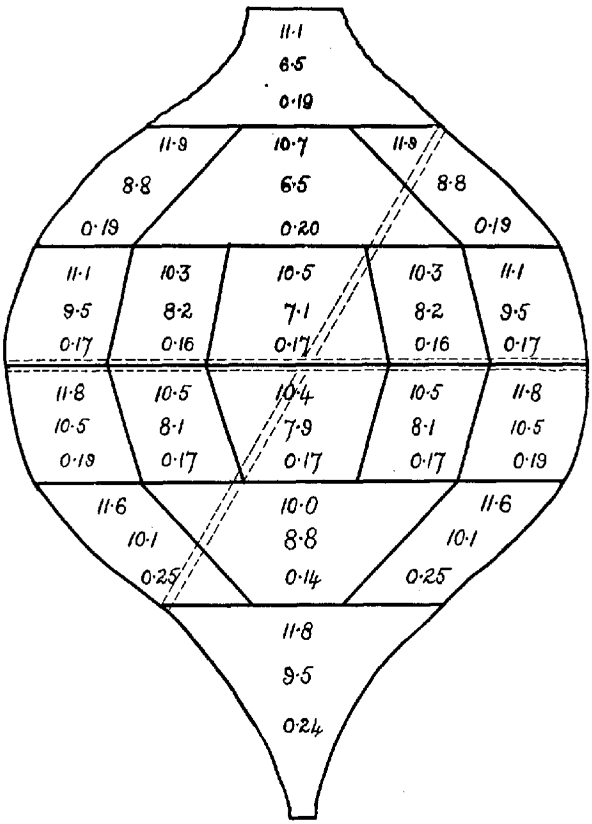


FIG. 1. Yellow-fleshed Globe.

In each "compartment the upper figure gives °/₀ of dry matter, the middle figure °/₀ of sugar, and the lower figure °/₀ of nitrogen.

The coring method of sampling roots may therefore be accepted as reliable, both in our own experience and that of the Continental sugar-beet workers.

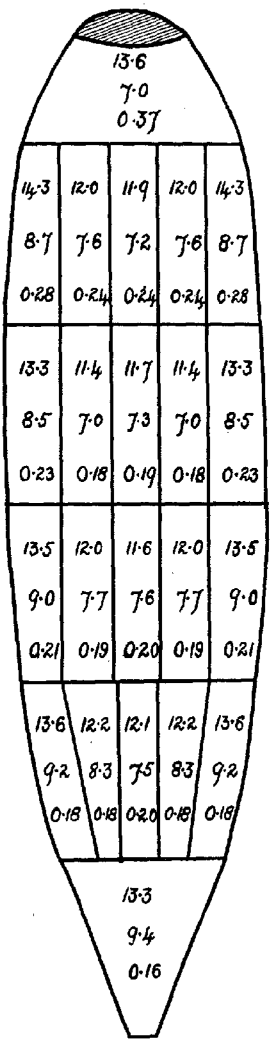


FIG. 2. Long Red.

In each "compartment" the upper figure gives °/₀ of dry matter, the middle figure °/₀ of sugar, and the lower figure °/₀ of nitrogen.

It has already been mentioned that roots are not uniform in composition throughout their substance, and it would therefore appear to be a matter of some importance that the core should be taken in a certain direction. We therefore divided a number of roots into four or five horizontal slices, each of which was further divided into concentric rings. The dry matter, sugar, and nitrogen were then determined in each piece, and the distribution of dry matter and sugar throughout the root was found to be as shown in the figures, pp. 180, 181. Fig. 1 shows the distribution in a Yellow Globe mangel, Fig. 2 in a Long Red. Other experimenters who have used the coring method for sampling roots have taken their cores diagonally through the centre of the root from a point just below the lowest leaf-scar. Examination of Figs. 1 and 2 shows that coring in this manner is liable to two sources of error—firstly, the root changes in composition very rapidly in the region just below the leaf-scars; and secondly, especially in the varieties possessing the long shape, the core is liable to contain much too large a proportion of the poorer quality of material near the centre of the root, and to give therefore low results. To obviate these risks we have taken our cores horizontally through the greatest diameter of the root, the region where variation in composition is least pronounced.

Having settled on the horizontal core for sampling individual roots, it was necessary to determine the number of roots which must be cored in order to obtain a mixed sample representing the composition of the crop. Many of the published analyses of root crops have been made on single roots, but as a rule larger numbers, up to 15 or 20, the numbers taken at Rothamsted, have been wholly or partially sliced or pulped and mixed. Our figures for individual variation were utilised to obtain some definite information on this point.

Table I, opposite, explains itself, and shows that, when using the coring method, samples taken from only 10 roots may give results differing from the mean by nearly $\pm$ 1 per cent. Even by sampling 20 roots the error may amount to $\pm$ 0·5 per cent., but by sampling 50 roots the error is reduced to $\pm$ 0·2 per cent. or under, and it would appear therefore that at least 50 roots should be cored in order to obtain a really representative sample. Much the same results are obtained by the sector method. All our work has been done on duplicate samples, each taken from 50 roots, and we have found the duplicates to agree quite satisfactorily, the average difference between about 200 duplicate determinations this year being under 0·3 per cent. for dry matter and under 0·2 per cent. for sugar.

TABLE I.

	Sampled by Cores			Sampled by Sectors
Average of consecutive tens				
Maximum.........	15·40	15·87	15·41	13·40
Minimum.........	13·56	14·61	13·60	12·06
Average............	14·70	15·27	14·53	12·76
Error..............	± ·92	± ·63	± ·86	± ·67
Average of consecutive twenties				
Maximum.........	15·15	15·65	14·84	13·24
Minimum.........	14·32	14·95	13·82	12·30
Average............	14·70	15·27	14·53	12·76
Error..............	± ·41	± ·35	± ·51	± ·47
Average of consecutive fifties				
Maximum.........	14·92	15·38	14·60	12·83
Minimum.........	14·47	15·21	14·49	12·69
Average............	14·70	15·27	14·53	12·76
Error..............	± ·22	± ·08	± ·05	± ·07

The samples of 50 cores from each plot are taken in the field, wrapped in butter-paper, labelled, and sent to the laboratory in tin boxes. They are prepared for analysis the next morning.

Analysis.

Each packet of 50 cores is first cut in halves transversely. One half is at once weighed on a tared shallow aluminium tray, and dried to constant weight at a temperature of 65° C. At this temperature the dry matter practically ceases to lose weight after 48, or at most 72 hours, and no discoloration or charring occurs.

The dried cores, after cooling, are weighed and at once ground in an analytical mill. The powder is further used for determination of nitrogen and other constituents.

The second half of the bundle of cores is reduced to pulp by passing through a small sausage mill. The pulp is placed in a piece of fine linen, and the juice at once squeezed out as completely as possible by hand. When first expressed the juice is light coloured, but frothy and full of air bubbles, and by the time these have risen an oxidase[1] contained in the juice has commenced to form a black precipitate in the upper layers. Specific gravity determination, or measuring, is therefore a matter of some delicacy. We have always taken care to measure the juice for analysis as soon as possible after the froth has subsided.

With these precautions 100 c.c. of juice is measured out, 10 c.c. of basic lead acetate solution added, the mixture shaken and filtered after standing some time. The clear filtrate is polarised at once, and again polarised after inversion by Clerget's method. The percentage of cane sugar is calculated from the change in rotation on inversion, and it is always found that the dextro-rotation of the original juice is rather more than is accounted for by the cane sugar present. The difference corresponds to from 0·1 to 0·5 per cent. of dextrose, an amount which agrees very well with figures given by Miller[2] in his paper on the changes in composition of mangels during storage.

To convert percentage of sugar in the juice into percentage in the root we have adopted the factor 0·93, which was arrived at as follows:

Mean of 90 determinations of specific gravity of juice............ 1·0393

Mean of 12 determinations of percentage of insoluble material in the root .... 3·04

Percentage of juice therefore $= 100 - 3{\cdot}04 = 96{\cdot}96$.

$$\text{Factor for converting percentage in juice into percentage in root} = \frac{96{\cdot}96}{1{\cdot}0393} = 0{\cdot}93.$$

This factor was confirmed by comparing the percentage of sugar in the juice determined as above explained, with the percentage in the root as determined by alcohol extraction.

	I.	II.	III.
Percentage total sugar in juice	7·40	6·80	7·10
Percentage total sugar in root by alcohol extraction	6·81	6·25	6·65
Factor	0·92	0·92	0·94

[1] Bertrand, *Ann. Agr.* XXIII. p. 385, 1897.
[2] *R.A.S.E. Journal*, III. XI. p. 57, 1900.

Nitrogen was determined in the finely ground dry matter by Kjeldahl's method, using sulphuric acid containing 5 per cent. of salicylic acid in order to prevent any possible loss of nitrogen due to decomposition of nitrates. Duplicates were found to agree very satisfactorily, the average difference being between 0·02 and 0·03 per cent. Some determinations were made of proteid nitrogen by precipitating the proteids from a suspension of the dry matter in water by means of copper acetate, and determining the nitrogen in the precipitate.

A few fibre estimations were made, using $1\frac{1}{4}$ per cent. sulphuric acid and $1\frac{1}{4}$ per cent. soda, but as the results did not seem to give information of any particular interest, the analyses were discontinued.

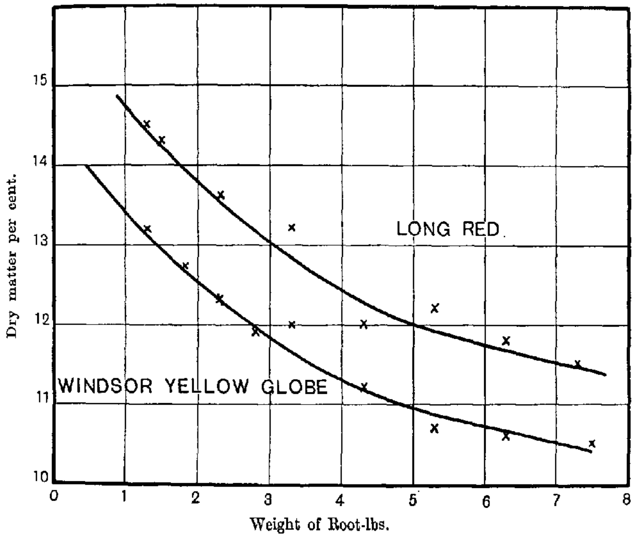


FIG. 3.

VARIATION DUE TO SIZE OF ROOT.

A factor which has to be considered in comparing the results of analyses of different samples of roots is the influence of the size of the root on the percentage of dry matter. It has already been mentioned that several writers and most text-books call attention to this point, and

state that large roots contain more water, and consequently less dry matter than smaller ones.

We have attempted to measure this effect of size by determining the percentage of dry matter in duplicate samples of 50 roots of varying sizes. The results are embodied in Fig. 3, p. 185, and they show that the influence of size is the same in both the varieties which were tried. The following figures give the decrease in dry matter due to each additional lb. in weight of root from 1 to 7.

Weight of root increases		Dry matter decreases by	
From lbs.	To lbs.	White-fleshed globe %	Long red %
1	2	0·9	0·9
2	3	0·7	0·7
3	4	0·5	0·6
4	5	0·4	0·4
5	6	0·25	0·3
6	7	0·2	0·2

It is noticeable that a small change in weight makes a great difference in percentage of dry matter if the roots are small, but when the size of the root attains something like 7 lbs., alteration in weight has a comparatively small effect on the percentage of dry matter. As most of the roots sampled were over 4 lbs. in weight, this factor cannot have caused any very great errors.

Classification of Varieties.

The catalogues of the leading seedsmen of the present day contain an enormous number of named strains of mangels, and in commencing an investigation on the chemical composition of mangels, the question at once arises as to how many of these seedsmen's names represent really distinct types.

The older literature[1] mentions only very few varieties, Long Red, with its sub-strain Hornbeet, so called from its being curved like a cow's horn; Long Yellow; and Red and Yellow Globes; and it was not until the last 20 years or so that the number of varieties has been so greatly multiplied. On comparing the botanical characteristics, and

[1] Wilson, *Our Farm Crops*, Vol. I. p. 407, Edinburgh, 1859; Raynbird, *R.A.S.E. Journal*, I. VIII. p. 217, 1847.

the chemical composition, of all the seedsmen's strains we have grown during our three years' work, we find that a large proportion of the strains which have been investigated fall into one or other of the varieties mentioned by the older writers, and one of the first results of our investigations was to show that there are five types of mangels in common cultivation, namely, White-fleshed Yellow Globe, White-fleshed Intermediate, Yellow-fleshed Tankard, Yellow-fleshed Globe, and Long Red, while a number of miscellaneous strains which we have not at present attempted to classify, are occasionally grown.

In the following Table II will be found the yield per acre, the percentages of dry matter, sugar, nitrogen, and fibre, in all the strains we have investigated.

The strains are classified into the above five types, with the exception of the above-mentioned miscellaneous strains which are given separately at the end of the table.

On looking through the analyses of the various strains of the same type grown side by side at the same station it will be seen that they all have the same composition within the limits of error of experiment. Thus in the White-fleshed Globes, the agreement in percentage of dry matter is very close among all the strains which have been grown on the University Farm each year. There were, however, considerable differences between the strains of this variety at Trowse and Saxlingham in 1902. At Saxlingham this was undoubtedly due to the fact that the roots were grown on a somewhat gravelly field which dried out in places where the roots attained only a very small size, with correspondingly high percentages of dry matter (see p. 185). At Trowse the cause of variation is probably different. Webb's New Smithfield, which contained a higher percentage of dry matter than the other strains of the same type, produced a very considerable proportion of roots containing yellow pigment in their flesh. These yellow-fleshed roots were picked out and sampled separately at Field Dalling in 1904, and they were found to contain ·6 per cent. of dry matter and ·4 per cent. of sugar more than the white-fleshed roots among which they were growing.

With regard to the Intermediates, they do not agree among themselves nearly so well as the other types. This point is discussed later.

The Yellow-fleshed Tankards agree among themselves very well, with a few exceptions at the University Farm in 1904, due again to some of the strains producing very small roots. The same remarks apply to Yellow-fleshed Globe and Long Red.

TABLE II.

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
White-fleshed Yellow Globe							
Carter's Windsor	University Farm	1902	37·7	11·7	6·9	·175	·71
Sutton's Prize Winner......	,,	,,	37·6	11·5	6·7	—	—
Webb's New Smithfield ...	,,	,,	36·2	11·5	7·2	—	—
Carter's Windsor	Trowse	,,	—	11·1	7·6	·149	·66
Sutton's Prize Winner......	,,	,,	—	10·3	6·2	—	—
Webb's New Smithfield ...	,,	,,	—	12·1	7·7	—	—
Carter's Windsor	Aylsham	,,	—	9·9	6·2	·174	·68
Sutton's Prize Winner......	,,	,,	—	9·7	5·7	—	—
Webb's New Smithfield ...	,,	,,	—	10·5	6·8	—	—
Carter's Windsor	Saxlingham	,,	—	11·5	7·7	·184	·69
Sutton's Prize Winner......	,,	,,	—	13·5	8·2	—	—
Webb's New Smithfield ...	,,	,,	—	12·5	8·1	—	—
Average...............	Four Stations	1902	37·2	11·3	7·1	·161	·69
Carter's Windsor	University Farm	1903	31·5	11·3	6·7	·116	—
,, ...	Trowse	,,	—	9·5	5·5	·162	—
,, ...	Aylsham	,,	—	8·5	4·6	·135	—
,, ...	Saxlingham	,,	—	9·6	4·8	·225	—
,, ...	Ridgmont	,,	—	11·0	6·7	·150	—
Average...............	Five Stations	1903	31·5	10·0	5·7	·158	—
Carter's Windsor	University Farm	1904	20·5	10·5	6·3	·170	—
Sutton's Prize Winner......	,,	,,	—	11·1	5·9	—	—
,, Devon	,,	,,	—	11·9	6·6	—	—
,, Yellow..............	,,	,,	20·4	11·6	6·6	—	—
Daniels' Norwich	,,	,,	—	11·9	7·2	—	—
Cannell'sQuantity&Quality	,,	,,	20·7	11·7	6·3	—	—
Carter's Windsor	Trowse	,,	—	11·2	5·7	·222	—
Webb's New Smithfield ...	,,	,,	—	11·1	6·1	—	—
Carter's Windsor	Aylsham	,,	21·7	9·6	5·2	·159	—
Webb's New Smithfield ...	,,	,,	21·8	10·3	6·4	—	—
Carter's Windsor	Ridgmont	,,	—	11·7	6·8	·164	—
,, ...	Field Dalling	,,	—	9·7	5·9	·159	—
Webb's New Smithfield ...	,,	,,	—	10·3	6·5	—	—
Carter's Windsor	Yeldham	,,	—	10·9	6·4	—	—
Sutton's Prize Winner......	,,	,,	—	11·0	6·4	—	—
Carter's Windsor	Hamels Park	,,	—	9·7	5·6	—	—
Average...............	Seven Stations	1904	21·1	10·9	6·2	·175	—
Three Years' Average......	....	....	29·9	10·7	6·3	·165	—
White-fleshed Intermediate							
Sutton's Yellow...............	University Farm	1902	33·5	13·2	8·1	—	—
Webb's Lion	,,	,,	35·7	11·8	6·9	—	—
Average...............	....	1902	34·6	12·5	7·5	—	—
Sutton's Yellow...............	University Farm	1903	28·5	12·7	8·0	·120	—
,, ...	Trowse	,,	—	10·7	6·6	·171	—
,, ...	Aylsham	,,	—	9·5	5·5	·160	—
,, ...	Saxlingham	,,	—	11·7	6·6	·213	—
,, ...	Ridgmont	,,	—	11·8	7·2	·171	—
Average...............	Five Stations	1903	28·5	11·3	6·8	·157	—

TABLE II.* (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
White-fleshed Intermediate (*continued*)							
Sutton's Yellow	University Farm	1904	18·6	12·5	7·7	·167	—
Daniels' Gate Post	,,	,,	—	13·6	8·4	—	—
Sutton's Devon Yellow	,,	,,	—	11·6	6·6	—	—
Sutton's Yellow	Trowse	,,	—	12·8	6·6	·229	—
,,	Aylsham	,,	19·6	11·5	6·4	·167	—
,,	Ridgmont	,,	—	11·9	6·5	·169	—
,,	Field Dalling	,,	—	10·7	6·5	·161	—
Average	Five Stations	1904	19·1	12·1	7·0	·179	—
Three Years' Average			27·4	12·0	7·1	·168	—
Yellow-fleshed Tankard							
Sutton's Golden	University Farm	1902	32·0	14·3	8·8	·162	·72
Webb's Yellow-fleshed	,,	,,	31·8	13·7	8·6	—	—
Sutton's Golden	Trowse	,,	—	13·6	8·7	·185	·77
,,	Aylsham	,,	—	12·5	8·4	·190	·81
,,	Saxlingham	,,	—	14·1	9·5	·240	·74
Average	Four Stations	1902	31·9	13·6	8·8	·194	·76
Sutton's Golden	University Farm	1903	25·8	12·9	8·2	·118	—
Webb's Yellow-fleshed	,,	,,	—	13·3	8·8	—	—
Sutton's Golden	Trowse	,,	—	12·3	7·6	·179	—
Webb's Yellow-fleshed	,,	,,	—	12·9	7·9	—	—
Sutton's Golden	Aylsham	,,	—	9·6	5·7	·161	—
Webb's Yellow-fleshed	,,	,,	—	10·5	6·1	—	—
Sutton's Golden	Saxlingham	,,	—	12·7	7·2	·247	—
Webb's Yellow-fleshed	,,	,,	—	13·3	7·6	—	—
Sutton's Golden	Ridgmont	,,	—	12·4	7·7	·126	—
Webb's Yellow-fleshed	,,	,,	—	12·4	7·9	—	—
Average	Five Stations	1903	25·8	12·2	7·5	·168	—
Sutton's Golden	University Farm	1904	18·3	13·4	8·3	·201	—
Cannell's Golden	,,	,,	12·0	14·2	8·2	—	—
King's Golden	,,	,,	—	15·5	9·1	—	—
Sutton's Golden	Trowse	,,	—	13·1	7·0	·235	—
,,	Aylsham	,,	18·3	12·5	7·1	·184	—
,,	Ridgmont	,,	—	13·5	7·9	·181	—
,,	Field Dalling	,,	—	12·0	7·0	·185	—
Average	Five Stations	1904	16·2	13·4	7·8	·197	—
Three Years' Average			24·6	13·1	8·0	·186	—
Yellow-fleshed Globe							
Sutton's Golden	University Farm	1902	31·1	14·6	9·6	·191	·76
Webb's Golden King	,,	,,	30·3	15·2	9·7	—	—
Carter's Goldfinder	,,	,,	32·0	14·9	9·1	—	—
Sutton's Golden	Trowse	,,	—	15·0	9·6	·216	·88
,,	Aylsham	,,	—	13·0	8·5	·207	·81
,,	Saxlingham	,,	—	14·2	8·7	·152	·78
Average	Four Stations	1902	31·2	14·4	9·2	·192	·81

TABLE II. (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
Yellow-fleshed Globe (*cont.*)							
Sutton's Golden	University Farm	1903	25·5	13·4	8·7	·137	—
Webb's Golden King.........	,,	,,	27·5	14·4	9·4	—	—
Carter's Goldfinder	,,	,,	—	12·9	8·5	—	—
Sutton's Golden	Trowse	,,	—	12·1	7·3	·194	—
Webb's Golden King.........	,,	,,	—	12·0	6·9	—	—
Carter's Goldfinder	,,	,,	—	12·1	7·2	—	—
Sutton's Golden	Aylsham	,,	—	11·0	6·9	·167	—
Webb's Golden King	,,	,,	—	10·6	6·3	—	—
Carter's Goldfinder	,,	,,	—	9·9	5·4	—	—
Sutton's Golden	Saxlingham	,,	—	12·9	7·5	·225	—
Webb's Golden King	,,	,,	—	12·4	6·8	—	—
Carter's Goldfinder	,,	,,	—	12·7	7·2	—	—
Sutton's Golden	Ridgmont	,,	—	12·9	8·1	·150	—
Webb's Golden King	,,	,,	—	13·0	8·0	—	—
Carter's Goldfinder	,,	,,	—	12·1	7·5	—	—
Average...............	Five Stations	1903	26·5	12·3	7·3	·175	—
Sutton's Golden	University Farm	1904	16·7	13·9	8·2	·227	—
Webb's Golden King	,,	,,	19·7	14·6	8·8	—	—
King's Golden	,,	,,	—	14·1	8·3	—	—
,, Orange	,,	,,	18·3	14·0	8·3	—	—
Cannell's New Century ...	,,	,,	16·3	14·7	8·8	—	—
Daniels' Coronation	,,	,,	15·5	14·6	9·1	—	—
Sutton's Golden	Trowse	,,	—	13·7	7·9	·251	—
,, ...	Aylsham	,,	17·4	12·2	7·3	·182	—
,, ...	Ridgmont	,,	—	13·2	8·3	·177	—
,, ...	Field Dalling	,,	—	11·9	7·5	·186	—
,, ...	Hamels Park	,,	—	11·8	7·4	—	—
Webb's Golden King	Yeldham	,,	—	14·8	9·1	—	—
Average...............	Seven Stations	1904	17·3	13·6	8·2	·205	—
Three Years' Average......	....	....	25·0	13·4	8·2	·191	—
Long Red							
Sutton's Mammoth	University Farm	1902	33·2	14·7	8·7	·154	·81
Carter's Mammoth	,,	,,	31·0	15·1	8·9	—	—
Sutton's Mammoth	Trowse	,,	—	13·6	8·4	·149	·77
,, ...	Aylsham	,,	—	11·9	7·6	·170	·82
,, ...	Saxlingham	,,	—	14·1	9·4	·152	·84
Average...............	Four Stations	1902	32·1	13·9	8·6	·156	·81
Sutton's Mammoth	University Farm	1903	34·7	13·5	8·5	·110	—
,, ...	Trowse	,,	—	12·4	7·4	·216	—
,, ...	Aylsham	,,	—	11·5	6·4	·127	—
,, ...	Saxlingham	,,	—	12·4	7·0	·182	—
,, ...	Ridgmont	,,	—	12·3	7·8	·084	—
Average...............	Five Stations	1903	34·7	12·4	7·4	·144	—
Sutton's Mammoth	University Farm	1904	20·7	13·2	7·8	·173	—
,, Elvetham	,,	,,	—	15·5	9·5	—	—
Sutton's Mammoth	Trowse	,,	—	13·1	7·2	·214	—
,, ...	Aylsham	,,	25·4	11·2	6·4	·164	—
,, ...	Ridgmont	,,	—	13·3	7·8	·156	—
,, ...	Field Dalling	,,	—	12·1	7·3	·143	—
,, ...	Hamels Park	,,	—	11·1	6·8	—	—
,, ...	Yeldham	,,	—	14·0	8·6	—	—
Average...............	Seven Stations	1904	23·0	12·9	7·7	·170	—
Three Years' Average......	....	....	29·9	13·1	7·9	·157	—

TABLE II. (*continued*).

Name of Variety and Strain	Where grown	Year	Yield per acre. Tons	% Dry Matter	% Sugar	% Nitrogen	% Fibre
MISCELLANEOUS:							
Long Yellow							
Sutton's	University Farm	1903	27·5	14·5	9·3	—	—
,,	Trowse	,,	—	12·4	7·4	—	—
,,	Aylsham	,,	—	11·4	6·5	—	—
,,	Saxlingham	,,	—	12·8	7·5	—	—
,,	Ridgmont	,,	—	13·6	8·6	—	—
Average	Five Stations	1903	27·5	13·0	7·9	—	—
Sutton's	University Farm	1904	13·1	14·7	8·8	—	—
Carter's	,,	,,	14·6	14·3	8·5	—	—
Average		1904	13·8	14·5	8·6	—	—
Crimson Tankard							
Sutton's	University Farm	1902	30·7	13·5	8·4	—	—
,,	,,	1903	—	13·4	8·0	—	—
,,	,,	1904	13·3	12·9	7·5	—	—
,,	Yeldham	,,	—	13·6	8·0	—	—
Average				13·3	8·0	—	—
Carter's **1901**	University Farm	1902	31·0	14·9	8·7	—	—
,,	Trowse	,,	—	14·7	9·2	—	—
,,	Aylsham	,,	—	12·8	8·0	—	—
,,	Saxlingham	,,	—	14·0	9·0	—	—
,,	University Farm	1903	—	12·8	7·8	—	—
Carter's **Red Globe**	University Farm	1904	—	16·7	10·3	—	—
,, **Red Emperor**	,,	,,	14·9	14·8	9·2	—	—
,, **Golden Intermediate**	,,	,,	12·1	12·7	7·1	—	—
Cannell's **Red Intermediate**	,,	,,	18·0	15·3	9·3	—	—
Webb's **Champion**	University Farm	1902	32·1	14·2	8·8	—	—
Daniel's **Berkshire**	,,	1904	—	13·4	8·4	—	—
,, **Somerset**	,,	,,	—	13·3	7·9	—	—
Sugar Mangel							
Carter's	University Farm	1902	27·9	16·0	10·9	—	—
,,	Trowse	,,	—	15·7	9·9	—	—
,,	Aylsham	,,	—	14·7	9·4	—	—
,,	Saxlingham	,,	—	15·8	11·0	—	—
Average	Four Stations	1902	27·9	15·6	10·3	—	—
Carter's	University Farm	1903	—	13·0	7·6	—	—
Sutton's	,,	,,	—	13·0	7·6	—	—
Average		1903	—	13·0	7·6	—	—
Carter's	University Farm	1904	13·5	15·4	9·2	—	—
Sutton's	,,	,,	18·3	15·3	9·2	—	—
Average		1904	15·9	15·4	9·2	—	—
Three Years' Average				14·7	9·0	—	—

Among the Yellow-fleshed Globes, Goldfinder and Golden King have generally given low results for dry matter and sugar. These two strains, like New Smithfield, do not come quite true, but produce a certain number of white-fleshed roots. These white-fleshed roots were picked out and sampled separately at the University Farm in 1904, and were found on analysis to contain 1·7 per cent. dry matter and ·7 per cent. sugar less than the yellow-fleshed roots of the same strain from the same plot.

The presence of a variable proportion of such white-fleshed roots in the plots of these strains may well account for their variability in composition.

We now proceed to give the characteristics of each of the five chief types in the light of the information contained in the above table.

White-fleshed Globe.

Characters. Root globe-shaped, with white flesh, skin yellow below ground, shading through white to green above. Leaves small, erect, and very bright green, with petioles which are usually greenish-white, but often turn yellowish as the season advances. Nearly every seedsman has several strains of this variety, which differ chiefly in purity, presumably because some of them have been more carefully selected than others.

All the strains are extremely vigorous and grow large crops of very uniformly shaped roots, but the percentages of dry matter, sugar, and nitrogen are low compared with other varieties.

White-fleshed Intermediate.

Characters. These are, on the whole, very similar to the characters of the White-fleshed Globe, with the following exceptions: The root is more elongated along its vertical axis than in the globe; the skin of the root and of the petioles is often more deeply pigmented; and the variety is not so vigorous, and grows usually rather smaller crops of less uniform shape, but containing higher percentages of dry matter, sugar, and nitrogen.

The various seedsmen's strains do not resemble each other nearly so closely as do the strains of White-fleshed Globe, nor does each strain come so true from seed.

These facts, and the absence of references to Intermediate in the older literature, suggest that it is probably a new variety which has not yet been selected for a long-enough period to secure uniformity.

Yellow-fleshed Tankard.

Characters. Root usually tankard shaped, but most strains produce

some globe-shaped roots; flesh yellow; skin shading from crimson at the base, through orange, to brownish near the crown; leaves larger than in White-fleshed Globe; petioles usually orange. There is a large number of strains of this type, which closely resemble each other. They do not crop nearly so well as the White-fleshed Globe, but contain considerably more dry matter, sugar, and nitrogen.

Yellow-fleshed Globe.

Characters on the whole very similar to the Tankards, the only difference being that the majority of the roots of this variety are globular in shape. There is a very large number of strains, which differ considerably in external characters, notably in the colour of the skin of the root and of the petioles. Those strains which have a less decided orange colour in skin and petioles do not always come true from seed, but produce a considerable proportion of white-fleshed roots (see p. 192). The cropping power and the chemical composition are on the average almost exactly the same as in Yellow-fleshed Tankard.

Long Red.

Characters. Root long and narrow; flesh pink; skin crimson or magenta, shading to brown near the crown; leaves dark green and erect. There are very few strains of this type, and all are extremely uniform. The pigment which they contain seems to be quite distinct from that of the yellow-fleshed varieties. We have noticed that it is completely precipitated when the juice is clarified with basic lead acetate in preparing for sugar estimation, whilst the yellow pigment is not. The Long Red grows very large crops on soils which suit it. On the average of our three years' trials its cropping power is just equal to that of Yellow-fleshed Globe, and it contains much more dry matter and sugar, but less nitrogen.

MISCELLANEOUS VARIETIES.

In the course of our work we have come across a number of mangels which cannot be included in either of the five types described above, and which we have not attempted to classify, either because they are not sufficiently widely grown to make it worth while, or because they are not fixed types, or because we have not as yet accumulated sufficient information about them. We therefore give our results with them as far as they go at present.

Long Yellow.

This mangel resembles Long Red in all characters except that it is coloured yellow instead of red. It appears to be quite a distinct and constant variety, but, so far as we know, is not widely grown.

It has not cropped quite so well in our trials as Long Red, but gives on the average about the same percentages of dry matter and sugar.

Crimson Tankard.

This too appears to be quite a distinct and constant variety, similar in every way except colour to the Yellow-fleshed Tankards.

Carter's 1901.

Characters. Practically those of Yellow-fleshed Globe.

This is quite an interesting strain, lately put on the market by Messrs James Carter & Co., who state that it has been produced by selecting roots of superior chemical composition for seed-mothers. The actual method of selecting is not stated, but the mother-roots were apparently picked out for high specific gravity of their juice, which we show (pp. 206 and 210) to be by no means a reliable criterion of high content of dry matter or sugar. That the method of selection was not successful in making improvement is shown by the following figures, which give the percentages of dry matter and sugar in Carter's "1901," and in the Yellow-fleshed Globes grown side by side with it at four stations in 1902.

	Average of 4 Stations	
	Dry matter %	Sugar %
Carter's 1901	14·1	8·7
Other yellow-fleshed Globes ...	14·4	9·2

Carter's Red Globe, Red Emperor, and **Golden Intermediate**, and **Cannell's Red Intermediate**, are new mangels which we have only grown once, and about which we have not at present sufficient information.

Webb's Champion, Daniel's Berkshire and **Somerset,** are more like White-fleshed Globe than anything else, but in our trials they have not come true. A very considerable proportion of the roots they produce are more or less yellow in the flesh, and contain rather higher percentages of dry matter and sugar than the typical strains of White-fleshed Globe.

Sugar Mangel.

Some years ago several Continental seedsmen produced sugar mangels by crossing sugar beet with different varieties of mangels, and English seedsmen have lately been following their example.

We have tried two strains, which are distinct in appearance, but very similar in composition. In 1902 Carter's Sugar Mangel gave very high percentages of dry matter and sugar at each of our four stations, but had a somewhat awkward shape and habit of growth, burying itself deeply in the ground, and at the same time it did not come true. From every plot of it we picked out roots which were deep pink, almost like a Long Red mangel, others which were pure white like a sugar beet, and others which were intermediate in colour. A very large proportion of the plants also ran to seed the first year. These defects have been less in evidence in 1903 and 1904.

SUMMARY OF CLASSIFICATION.

In the following table are collected the three years' averages at all stations of all the strains of the five chief types which have been grown:

Name of Type	Yield per acre. Tons	Dry matter %	Sugar %	Nitrogen %
White-fleshed Globe	29·9	10·7	6·3	0·165
White-fleshed Intermediate ...	27·4	12·0	7·1	0·168
Yellow-fleshed Tankard.........	24·6	13·1	8·0	0·186
Yellow-fleshed Globe	25·0	13·4	8·2	0·191
Long Red	29·9	13·1	7·9	0·157

These figures summarise the remarks already made about the chemical composition of each type. From them can be calculated the yield of actual dry food per acre produced on the average by each variety. This is done below:

Name of type	Dry matter per acre. Tons	Sugar per acre. Tons	Nitrogen per acre. lbs.
White-fleshed Globe	3·20	1·88	111
White-fleshed Intermediate ...	3·29	1·94	103
Yellow-fleshed Tankard.........	3·22	1·96	102
Yellow-fleshed Globe	3·35	2·05	107
Long Red	3·92	2·36	105

Inspection of the figures in the above table shows extraordinary similarity in yield of dry matter, sugar, and nitrogen per acre in all the types except Long Red, which stands out by itself as producing rather more than half a ton per acre of dry matter in excess of any of the other types. In the other four types cropping power and percentage of dry matter appear to be practically inversely proportional, but Long Red crops as heavily as White-fleshed Globe, and contains as much dry matter per cent. as Yellow-fleshed Globe and Tankard. Consequently it is the type which produces most dry food per acre.

Another point of interest in comparing the different types is the relative composition of their dry matter. Figures dealing with this subject are given below:

Name of Type	Composition of dry matter	
	Sugar %	Nitrogen %
White-fleshed Globe	59	1·52
White-fleshed Intermediate ...	59	1·46
Yellow-fleshed Tankard.........	61	1·45
Yellow-fleshed Globe	61	1·45
Long Red..	60	1·23

There is evidently very little variation as regards the average percentage of sugar in the dry matter of the different varieties, the white-fleshed varieties produce on the average a slightly less sugary, and rather more nitrogenous, dry matter than the yellow or red-fleshed kinds. Long Red contains exactly the average proportion of sugar, but is very distinctly less nitrogenous.

Feeding experiments are in progress at the present time with the object of testing the practical feeding value, if any, of these differences in composition of dry matter.

During the last few years several investigations on mangels have been published, both in England and on the Continent, which may in some respects be compared with our own work. In order to make the figures as comparable as possible, we have recalculated them all to a uniform basis by taking the average yield and composition of the White-fleshed Globes in each case as 100.

We are thus able to compare our results with those obtained by Druce at Holmes Chapel in Cheshire[1], by Foulkes at Harper-Adams

[1] *Report of Holmes Chapel Agric. and Hortic. School, Cheshire, C. C.* 1900.

College in Shropshire[1], by Paturel in Finisterre[2], and by Wohltmann at Poppelsdorf in Germany[3].

The comparative figures are given in the annexed table:

Name of Type	Relative Cropping Power, White-fleshed Globe = 100									
	Cambridge University				Holmes Chapel	Harper Adams		Finisterre	Poppelsdorf	
	1902	1903	1904	Av.	1900	1903	1904	1897	1904	Av.
White-fleshed Globe	100	100	100	100	100	100	100	100	100	100
White-fleshed Intermediate	93	91	90	91	89	73	91	90	102	89
Yellow-fleshed Tankard	86	82	77	81	77	73	79	71	81	76
Yellow-fleshed Globe	84	84	82	83	75	63	82	70	—	72
Long Red	86	110	108	101	88	—	94	100	—	93
	Relative Richness in Dry Matter, White-Fleshed Globe = 100									
				Av.						Av.
White-fleshed Globe	100	100	100	100	100	100	100	100	100	100
White-fleshed Intermediate	110	113	111	112	108	100	93	108	114	105
Yellow-fleshed Tankard	120	122	123	122	122	128	120	155	136	132
Yellow-fleshed Globe	127	123	125	125	129	121	112	143	—	126
Long Red	123	124	119	122	109	—	103	120	—	111

Our figures for both cropping power and relative richness in dry matter are very fairly uniform from year to year, and the average, representing as it does the results of three years at a number of stations, is probably quite reliable as showing the relative merits of the five varieties. It will be noticed that the average of the results of the other four workers quoted agrees fairly well with our own average. There are, however, discrepancies in the results of individual workers, for instance, the low figure for dry matter in Intermediate at Harper-

[1] *Reports of Harper-Adams Agric. Coll.* 1903–4.

[2] *Ann. Agron.* xxiv. p. 97, 1898.

[3] *Illust. Land. Zeit.* xxiv. Dec. 1904.

Adams College in 1904, and the high figure for dry matter obtained by Paturel and Wohltmann for Tankard and Yellow-fleshed Globe.

These discrepancies are probably due to errors in sampling: thus at Holmes Chapel the number of roots taken for sampling was only 12, Paturel took only four roots, Wohltmann averaged the analyses of only three roots for dry matter and nine for sugar. We have no information as to the number of roots sampled at the Harper-Adams College.

SEASONAL VARIATION.

It has already been mentioned that the figures for the Rothamsted mangel plots vary very greatly from year to year.

The extent of the variation is very large, from 8·82 per cent. dry matter on the dung, superphosphate, and nitrate plot in 1895 to 15·39 per cent. on the same plot in 1887. It is noteworthy that the crop also differed widely in these two years. In 1887 it amounted on the plot in question to not more than 3·1 tons per acre, while in 1895 the crop on the same plot was 20·35 tons.

On plotting the percentage of dry matter and the crop per acre side by side it is seen that very frequently a large crop means a low percentage of dry matter, and *vice versâ*, but not always, as for instance in 1899, when the crop was only 12 tons per acre, and the dry matter only 9·49 per cent., and again in 1889, when both crop and dry matter were high, 33·95 tons per acre and 12·93 per cent. It appears therefore that, while the conditions of season which tend to produce large crops generally also produce crops containing low percentages of dry matter, yet conditions may occasionally arise which produce large crops with high percentages of dry matter, and small crops with low percentages.

The year 1895, when the percentage of dry matter was lowest, was characterised by a wet, cold, sunless summer, while in 1887, when the dry matter was highest, the summer was extremely hot, and rainless for long periods.

Broadly speaking, a wet summer is likely to produce roots of low dry matter, a dry one roots with much dry matter.

Our figures for the three seasons 1902, 1903, and 1904 agree quite well with this supposition. The figures for crop per acre, dry matter, percentage of sugar and nitrogen in the dry matter, and rainfall during the summer months for the three years in question are given below.

Crop, Composition, and Rainfall.

Average of all plots at all stations.

Year	Crop per acre. Tons	Dry Matter °/o	Percentage in Dry Matter		Rainfall, May to September	Rainfall, May and June	Rainfall, July, August and September
			Sugar	Nitrogen.			
1902	33·7	13·1	64	1·34	10·75	6·31	4·44
1903	29·4	11·6	60	1·38	16·38	6·62	9·76
1904	19·3	12·6	58	1·53	8·08	2·33	5·75

1902. The spring of this year was showery, and the early summer rainfall was sufficient in quantity and regularly distributed, so that a good plant was obtained on all the plots, and an excellent early growth was made. August again was showery, and the good growth was continued, which ensured a good crop. September was dry and sunny and very favourable for ripening, which accounts for the high percentage of dry matter containing much sugar and little nitrogen.

1903 was also a favourable year for obtaining a plant, but the summer was wet and sunless, and growth was therefore slow. The autumn was also wet and cold, and consequently bad for ripening. The absence of sun caused the roots to remain small, and give therefore a low yield per acre, and the wet, cold autumn preventing ripening, gave low dry matter containing less sugar and rather more nitrogen than the 1902 crop.

1904 was characterised by deficient rainfall in the early summer, which made many blanks in the plant and checked the early growth. Favourable weather was experienced in August and September, and growth continued so late that ripening was imperfect. The early check prevented all chance of a good crop, and the late ripening caused the roots to be low in dry matter and sugar and high in nitrogen.

Summarising the results of the three years, the crop seems to depend on suitable rainfall in the early summer and again in early autumn, and warmth and sun are also required; high dry matter and sugar and low nitrogen are produced by warm, sunny, dry weather for the ripening of the roots in September.

MANURIAL VARIATION.

It is generally taken for granted that the manuring of mangels causes a great variation in composition, and that this is so under certain circumstances is shown by examination of the following figures extracted from Rothamsted *Memoranda*, 1901, and from information given by Mr A. D. Hall.

Manuring per acre	Yield per acre. Tons*	Dry Matter† %	Weight of root. lbs†.	Total Sugar in Dry Matter† %
Farmyard Manure, 14 tons per acre	17·4	13·4	2·44	67
Farmyard Manure + 3 cwt. Super. + 4½ cwt. Sulphate of Potash + 5 cwt. Nitrate of Soda	25·2	11·6	3·95	59
3½ cwt. Super. + 5 cwt. Nitrate of Soda	15·4	11·9	2·47	63
3½ cwt. Super. + 4½ cwt. Sulphate of Potash	4·5	14·9	·74	67
3½ cwt. Super. + 4½ cwt. Sulphate of Potash + 5 cwt. Nitrate of Soda	15·4	11·8	3·16	67

* Average, 1876–1900. † Average, 1900 and 1902.

Certain points stand out clearly; for instance, mineral manures alone have made very little increase in the crop, and correspondingly little decrease in the percentage of dry matter. Nitrogenous manures have when used with minerals made great increases in the crop and great decreases in the percentage of dry matter. Farmyard manure has acted as a nitrogenous manure, and has both increased the crop and decreased the dry matter.

It appears therefore that any manuring which increases the crop tends to decrease the percentage of dry matter, and, as the figures show, the percentage of sugar in the dry matter.

It is noteworthy that as the size of root has increased under manuring, the percentage of dry matter has decreased. The extreme variation in weight of root, 3·2 lbs., corresponds according to the diagram (p. 185) to a variation in content of dry matter of 2½ per cent. The figures in the above table show a variation of 3·3 per cent. in content of dry matter, which is considerably greater than would be caused by variation in size. It would appear therefore that manures affect the composition in some way other than by merely altering the size of root, and this is indicated also by comparison of plots getting farmyard manure alone and superphosphate and nitrate alone, the former producing roots with higher percentage of dry matter though of the same

size. Probably this outside influence is the imperfect ripening resulting from the excessive dressing—5 cwt.—of nitrate of soda.

From the above paragraph it is evident that manurial treatment may, under the exceptional conditions of the Rothamsted plots, become a very important factor in the composition of the mangel crop.

These conditions, continuous growth of mangels on the same plot year after year with the same manure, do not, however, occur in ordinary practice, and it remains to be seen how far manuring influences the composition of mangels grown in the course of ordinary farming.

We carried out trials on this point in 1903 at the University Farm, and a more complete trial at four stations in 1904.

The figures are given below:

UNIVERSITY FARM, 1903.

Manuring per acre	Dry Matter °/o	Sugar °/o	Nitrogen °/o
Farmyard Manure, 10 tons	13·8	8·8	0·128
Farmyard Manure + 40 lbs. N. + 25 lbs. P_2O_5 + 25 lbs. K_2O	12·9	8·2	0·130
Farmyard Manure + 40 lbs. N. + 100 lbs. P_2O_5 + 80 lbs. K_2O	13·0	8·3	0·131
40 lbs. N. + 100 lbs. P_2O_5 + 80 lbs. K_2O	13·3	8·5	0·136

The 1903 results bring out several points—the variation with different manuring in the ordinary course of farming is quite small compared with that found at Rothamsted, but in the same direction. Thus the addition of artificials to farmyard manure decreased the percentage of dry matter and sugar; and the excessive amount of nitrogen used with the farmyard manure, without enough phosphate and potash to balance it, gave the lowest percentage of dry matter, no doubt again on account of delayed ripening.

The 1904 results Table III at five stations are very satisfactory. The effects of the manures, both on yield per acre and on composition, are very concordant at the different stations, and the average results show that every manuring has given more or less increase in crop and more or less decrease in dry matter and sugar. Farmyard manure especially has been active in decreasing the percentage of dry matter and of sugar, and the dry matter of the roots grown on the farmyard manure plots contains a lower percentage of sugar than that of the artificially manured plots.

TABLE III. Crop Results and Analyses, 1904.

Manuring per acre	University Farm			Warham Norfolk		Hethersett Norfolk		Lydgate Suffolk			Eldo House Suffolk			Average				
	Yield per acre. Tons	Dry Matter %	Sugar %	Dry Matter %	Sugar %	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Yield per acre. Tons	Dry Matter %	Sugar %	Sugar in Dry Matter %	Weight of Root in lbs. at all Stations
Unmanured	14·5	13·5	7·7	12·3	7·1	14·1	9·0	4·8	15·5	8·7	12·8	16·8	11·0	10·7	14·4	8·7	60	2·2
40 lbs. N. .... 80 lbs. P_2O_5......... 80 lbs. K_2O.........	23·0	12·1	7·3	11·6	6·5	13·3	7·9	9·6	15·0	8·9	15·7	16·5	10·9	16·1	13·6	8·3	61	3·0
40 lbs. N. .... 80 lbs. P_2O_5.........	19·5	12·5	7·5	11·8	6·6	13·4	7·6	8·2	15·8	8·2	14·0	17·1	11·0	13·9	14·1	8·2	58	2·9
40 lbs. N. .... 80 lbs. K_2O.........	21·3	12·2	7·1	12·0	7·1	12·9	7·5	5·9	15·6	9·1	15·1	16·8	10·8	14·1	13·9	8·3	60	2·9
80 lbs. P_2O_5......... 80 lbs. K_2O.........	20·5	13·2	8·0	12·4	6·9	13·3	8·1	8·6	14·6	8·6	13·2	17·2	11·2	14·1	14·1	8·6	61	2·8
Farmyard Manure, 12 tons	22·5	10·7	6·2	10·7	5·8	11·1	6·0	8·3	14·1	7·9	13·9	16·4	10·5	14·1	12·6	7·3	58	3·1
Farmyard Manure +40 lbs. N. ... 80 lbs. P_2O_5... 80 lbs. K_2O...	28·9	10·7	6·2	10·6	6·0	10·2	5·1	9·8	13·8	7·8	17·9	15·5	9·9	18·9	12·2	7·0	57	3·0

The weight of the roots on the different plots was very fairly uniform, and the difference in size was not nearly enough to account for the difference in composition.

The greatest variation is quite small compared with the Rothamsted figures, but with farmyard manure and artificials the decrease in the percentage of dry matter is still quite considerable. In spite of this decrease the farmyard manure increased the crop so much that it produced more dry matter per acre. Thus:

	Tons.
Dry matter per acre grown with mixed artificials	2·2
,, ,, ,, ,, ,, + farmyard manure	2·3

VARIATION WITH SOIL.

During the three years over which our work has already extended we have grown mangels at seven stations, and every year certain stations have produced roots which have been consistently high or low in content of dry matter, sugar, or nitrogen, as can be seen from the following table.

Station	1902 Average of			1903 Average of			1904 Average of			Average of 3 years		
	8 varieties		4 vars.	9 varieties		5 vars.	5 varieties					
	Dry Matter °/₀	Sugar °/₀	Nitrogen °/₀	Dry Matter °/₀	Sugar °/₀	Nitrogen °/₀	Dry Matter °/₀	Sugar °/₀	Nitrogen °/₀	Dry Matter °/₀	Sugar °/₀	Nitrogen °/₀
University Farm	13·6	8·4	·171	13·2	8·4	·120	12·7	7·2	·187	13·2	8·0	·159
Trowse	13·3	8·4	·175	11·8	7·1	·184	12·8	6·9	·230	12·6	7·5	·196
Aylsham	11·9	7·6	·184	10·3	5·9	·150	11·4	6·5	·171	11·2	6·7	·168
Saxlingham	13·6	8·9	·173	12·3	6·9	·213	—	—	—	—	—	—
Ridgmont.........	—	—	—	12·4	7·7	·117	12·7	7·4	·169	—	—	—
Field Dalling ...	—	—	—	—	—	—	11·3	6·8	·167	—	—	—

As regards dry matter, examination of the table shows that the University Farm has consistently produced roots of high quality, while Aylsham has just as consistently produced roots of low quality, and Trowse has, except in 1904, been intermediate. The extreme variation between the stations has been from 1·5 to 3 per cent., and the question at once arises, is this variation correlated with varying size of root?

Unfortunately the roots were not weighed in 1902 and 1903, but in 1904 we took the precaution to weigh the 100 roots which were cored for each pair of samples, and for this year therefore we can compare the average size of root at each station with the percentage of dry matter, as is done in the following table:

WEIGHT OF ROOT AND DRY MATTER, 1904.

	Trowse	University Farm	Aylsham	Field Dalling
Weight of Root—lbs.	3·4	3·6	5·2	5·7
Dry Matter °/o.........	12·8	12·7	11·4	11·3

It is evident at once that as the average weight of root increases the percentage of dry matter decreases, and, taking the extremes, an increase of 2·3 lbs. in average weight of root corresponds with a decrease of 1·5 per cent. of dry matter. Referring to the curves connecting weight of root and dry matter on page 185, it will be seen that an increase in weight of root from 3·4 lbs. to 5·7 lbs. corresponds to a decrease in dry matter of 1·1 per cent.

The 1904 figures therefore appear to indicate that the variation in percentage of dry matter from one farm to another is largely to be explained by varying size of root. It must be remembered that these figures refer to one year only, and we do not therefore feel justified in stating that varying size of root explains everything in this connexion, especially as the figures show that the dry matter at the different stations has a varying composition, as is shown below.

Station	Percentage in Dry Matter	
	Sugar	Nitrogen
University Farm.........	62	1·24
Trowse	59	1·62
Aylsham	59	1·54
Saxlingham	60	1·61
Ridgmont..................	61	1·16

Thus the dry matter of the roots grown at the University Farm and at Ridgmont is characterised by a high percentage of sugar and a low

percentage of nitrogen, while Trowse, Aylsham, and Saxlingham produced roots whose dry matter was, on the contrary, rich in nitrogen and relatively poor in sugar.

We are extending this branch of our investigation to other types of soil, and hope this year to grow mangels on peats and on clay soils. In the meantime it may be of interest to record the following partial analyses of the soils on which we have already worked.

Station	Percentage in Air-dried Soil			
	Water	Organic Matter	Particles over ·2 mm.	Particles ·2—·04 mm.
University Farm.........	2·80	5·4	39·1	15·1
Saxlingham	0·70	3·7	51·1	31·6
Field Dalling	0·69	8·3	49·1	16·7
Ridgmont..................	6·90	6·4	36·5	8·3
Trowse	0·86	3·8	58·0	20·8
Aylsham	0·85	3·9	33·3	35·4

INDIVIDUAL VARIATION.

In discussing the question of sampling we have already had occasion to mention the occurrence of very considerable variation in the chemical composition of individual roots of the same strain, even when grown side by side in the same field.

Thus in 1902 we found in 200 individual roots of Sutton's Golden Globe four roots containing less than 11 per cent. of dry matter and four roots containing over 18 per cent. Similar results were also obtained in the same year with Webb's Golden King and with Carter's 1901.

A plant which varies as much as the above figures indicate ought to be capable of rapid improvement by careful selection. Such an improvement has been brought about in the case of the sugar beet. About 50 years ago Ventzke suggested that sugar-beet workers were selecting for shape and other external characters, and neglecting the really important point, namely the sugar content. Very soon afterwards Vilmorin commenced selecting sugar beet for composition, his first method being to pick out for seed-mothers roots of high specific gravity. This method he soon changed, and began to select for high specific gravity of juice. About this time Anderson, whose paper has

been already quoted, proposed this method for selecting swedes. His figures are plotted on the annexed diagram (Fig. 4), which shows that high specific gravity of juice is by no means an accurate measure of percentage of dry matter. Scheibler in 1867 showed that specific gravity is not a reliable criterion for selection, as it is so greatly influenced by included air and other sources of error.

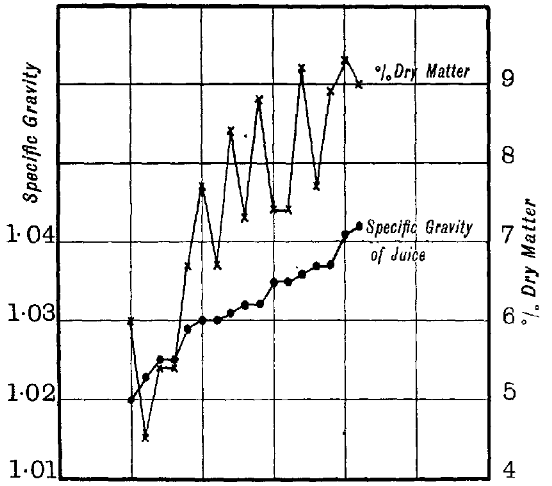


FIG. 4.
Plotted from Anderson's figures.

In 1867 Marek suggested that in selecting there should be an actual determination of the percentage of sugar in the juice by means of the polarimeter, and that, in order to increase the sugar without increasing the other solids of the juice, which interfere with the crystallisation of the sugar, the percentage of total solids in the juice should also be determined, and the sugar calculated as percentage of the total solids, or quotient of purity as it is called. The actual selection is then made for high percentage of sugar combined with high quotient of purity.

The above short outline of the development of the methods of sugar-beet selection is taken from Briem's *Der Praktische Rübenbau.* The success of this method of selection is shown by the following figures, which represent the average percentage of sugar in sugar-beet juice as calculated from figures found in the *Jahresbericht über Agricultur Chemie.*

Side by side with them are printed figures for the percentage of dry matter in mangels, similarly calculated except for the figure for 1852, which is taken from the tables of analyses in the *R.A.S.E. Journal* for that year.

SUGAR BEET				MANGELS			
Year	Sugar in Juice %	Year	Sugar in Juice %	Year	Dry Matter %	Year	Dry Matter %
1860–61	10·93	1882–83	13·60	1852	11·5	1895–1900	11·80
1868–69	11·34	1885	14·00	1880–84	10·97	1902	12·9
1870–72	11·80	1886	15·00	1885–89	11·78	1903	11·8
1873–74	12·65	1889	15·04	1890–94	13·04	1904	12·3

These figures bring out several important points. For instance, the steady improvement of the sugar beet from about 1870, when chemical selection was established on a satisfactory basis, is very apparent, and contrasts markedly with the constancy in the composition of mangels during the last 50 years.

The sugar beet has been selected for a definite purpose, and great improvement for that purpose has been brought about. The mangel has been selected also, but selection has been made for such external characters as shape, colour, size, rather than for improved chemical composition. The result is that we now have many strains of improved shape, colour, size, and so on, but the average percentage of dry matter remains much as it was 50 years ago.

The question now arises—is it possible to improve the mangel in quality, and if so, how must selection be carried out?

The first point is to decide what particular quality we want to improve. Mangels are grown almost entirely for food for cattle and sheep, and unfortunately there is very little definite information to be found as to the feeding value of the separate constituents of roots. In Danish experiments, carried out with pigs in 1895–8, the feeding value of roots was found to depend practically on the percentage of total dry matter[1], and the same result was arrived at in experiments at Cockle Park in 1902–3[2]. It would appear therefore that selection for high

[1] *Report of Royal Vet. and Agr. Lab. Copenhagen*, 1899. Quoted from *Expt. Stn. Record*, XI. p. 68.

[2] *Seventh Annual Report, Northumberland Demonstration Farm.*

content of dry matter would probably improve the feeding quality, and we have already commenced selecting in this direction as an experiment.

The feeding value of the various constituents of roots seems to need further investigation, and the University Department of Agriculture has experiments already in progress which it is hoped will throw more light on the subject. In the meantime, since selection can only be made in those directions in which variation occurs, we have studied the individual variation of several characters such as percentages of dry matter, sugar, and nitrogen, selection for which might bring about improvement, and colour, shape, specific gravity of juice, which might be correlated with some useful character, and which might therefore aid in selecting.

The annexed diagram (Fig. 5) shows the variation among 100 individual roots of a strain of Yellow-fleshed Globe, all grown side by side at the University Farm in 1903. They are plotted in ascending order of dry matter per cent., and the points marked on the same vertical line give the following characters from the top of the diagram downwards: Weight of root in lbs.; percentage, in the root, of dry matter and sugar; specific gravity of the juice; colour of the juice after clarifying with basic lead acetate; percentage in the root of total nitrogen $\times$ 6·25, and of proteid nitrogen $\times$ 6·25.

The dry matter was determined by drying a vertical sector representing about a quarter of the root; the sugar by polarising the juice before and after inversion, and correcting by the factor ·93 (see p. 184); the colour by comparing with arbitrary standards in a Lovibond tintometer; the total nitrogen by Kjeldahl's method in the dry matter; and the proteid nitrogen by the copper acetate method in the dry matter.

Examination of the diagram shows at once a great variation in percentage of dry matter—from 8·8 to 15·5 per cent.—and the curve shows all the usual features of a variation curve, a few very bad individuals, a few very good, and the rest intermediate.

The relation of the characters to each other is not very clear, and it will be necessary to consider them in detail.

Dry matter and weight. Following the curves for these two characters across the diagram, it is seen that on the whole there is a tendency for the weight of the root to fall as the dry matter rises, and this is what we should expect from the figures given on p. 186, but it is also evident that, while 50 large roots will always contain a lower percentage of dry matter than 50 small ones grown under the same conditions, yet it is by no means true that every large root is low in dry matter. Several

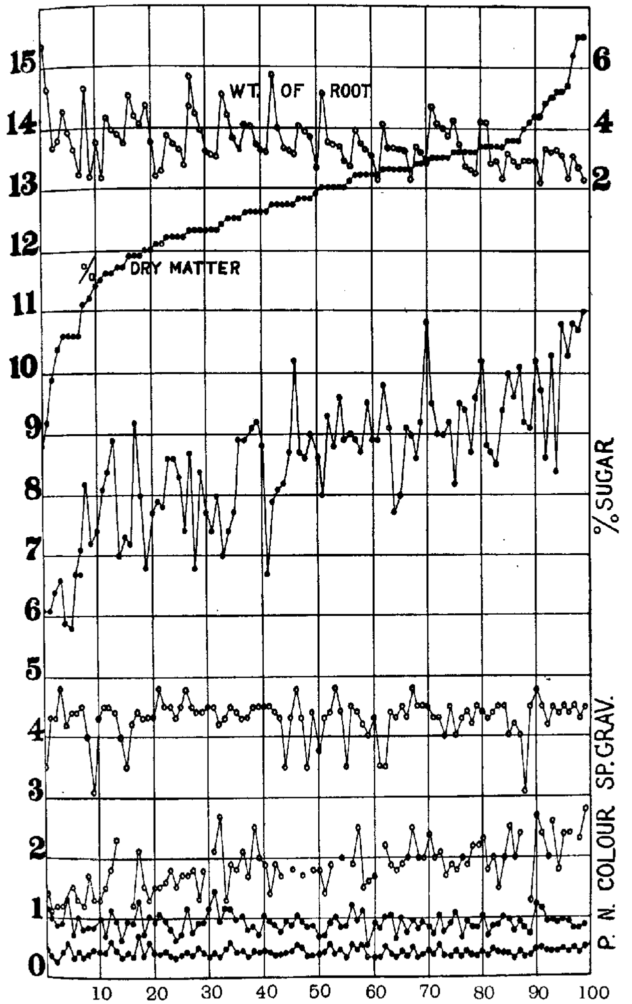


Fig. 5.

P = proteid Nitrogen % × 6·25.
N = total Nitrogen % × 6·25.

individuals can be picked out in the diagram which are 5 lbs. or over in weight, and contain 13 per cent. or more of dry matter. There should be no difficulty in selecting such roots as these for seed-mothers, and continuous selection in this manner should result in raising the percentage of dry matter without decreasing the cropping power.

Sugar. Again in the case of sugar there is evidently some correlation with dry matter, for it is evident from the curves that roots with high dry matter content contain much sugar, but the sugar forms by no means a constant proportion of the dry matter in every individual, varying from 81 per cent. to as little as 53 per cent.

It should thus be quite easy to continuously select for high dry matter which contains large or small proportions of sugar, whichever further work shows to be desirable.

Nitrogen. Neither total nor proteid nitrogen seems to be correlated with any other character, nor very closely with each other. Individuals can be picked out on the diagram with high dry matter and high total and proteid nitrogen, and it should therefore be possible to select continuously for high dry matter containing relatively much proteid if further work should indicate that the amount of proteid in roots is a serious factor in their feeding value. Looking at the diagram it will be seen that the range of variation in proteid is from ·71 per cent. to ·29 per cent., a difference which would mean nearly half a pound of proteid a day more or less in the daily ration of say 1 cwt. of roots used for a fattening steer. Half a pound more proteid in the ration of roots would allow quite a sensible diminution in the cake bill, so that the feeding value of the nitrogen in roots appears to be a point worth further investigation.

Specific gravity of juice. If specific gravity of juice could be shown to be anything like an accurate measure of either percentage of dry matter or percentage of sugar, it would provide by far the easiest way of selecting. It has already been pointed out that this was suggested in the early days of sugar beet selecting, and by Anderson for selecting turnips, but that the method has so many sources of error—air bubbles, action of oxidase, and so on—that it cannot be made of use in practice. The curve for specific gravity of juice on the diagram shows no relation to the other curves, and it is clear that from the specific gravity of the juice no certain inference can be made as to percentage of any constituent. Selection by this method therefore is likely to lead to disappointment.

Colour. In the earlier sections of this paper dealing with varieties,

it is noticeable that the varieties with deeply coloured flesh are highest in dry matter and sugar, and we decided therefore to record the colour of the 100 individuals we were examining for variation, in the hope that we might find some correlation between high colour and high percentage of dry matter. The colour is so unevenly distributed through the root that it is impossible to judge of its intensity satisfactorily. We decided therefore to measure the colour of the juice when clarified ready for

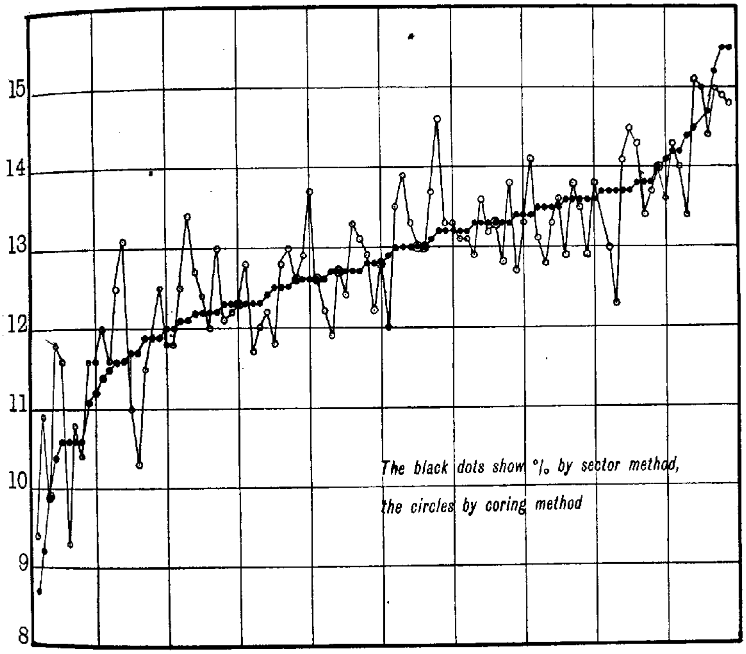


FIG. 6.

polarisation. This method agrees quite well with the colour of the ground dry matter, which we have also measured in some cases. The colour curve in the diagram gives no indication of any such correlation as we hoped to find.

Shape also was recorded in the case of each root, and it was found that out of the 100 roots, 17 having a very distinct spherical shape

averaged 12·9 per cent. dry matter, 18 which approximated more nearly to the tankard shape averaged 12·8 per cent., and 18 which were what may be called heart shaped also averaged 12·8 per cent., so that shape does not appear to have any definite connexion with percentage of dry matter.

It appears therefore that in the present state of our knowledge the method of selection most likely to result in improvement in the feeding value of mangels is selection for high percentage of dry matter, and that in making this selection reliance must not be placed on shape, colour, or specific gravity of juice, but the dry matter in each individual root must be actually determined.

We have already shown that the coring method of sampling gives reliable results for dry matter in samples taken from at least 50 roots. Obviously this is the only method which can be used for selecting, since any other method, such as the sector method, would damage the root too much for future seed growing. It is therefore necessary to test the coring method for single roots, and we have done this in the case of the 100 roots which were examined for individual variation. Before removing the sector a horizontal core was taken through the greatest diameter of the root, and both the core and the sector were dried side by side. The annexed diagram (Fig. 6) shows the results of the two series of determinations. It is evident that coring does not give entirely satisfactory results, especially with roots containing low percentages of dry matter, where the difference from the sector method occasionally amounts to as much as 1 per cent. For the higher percentages the two methods agree much more closely; thus the average error of the whole series is ·46 per cent., of the 50 roots lowest in dry matter ·51 per cent., and of the 50 highest in dry matter ·40 per cent.

An error of such magnitude might prevent the selection of the root highest in dry matter, but with a range of variation of between 7 and 8 per cent., the method would still be good enough to ensure the selection of roots which were certainly very much above the average.

There are several obvious sources of error in the method, as for instance the squeezing out of a little juice from the core on account of the narrowness and lack of uniformity of bore of the coring instrument. These we are endeavouring to remove, and we hope to improve the method considerably.

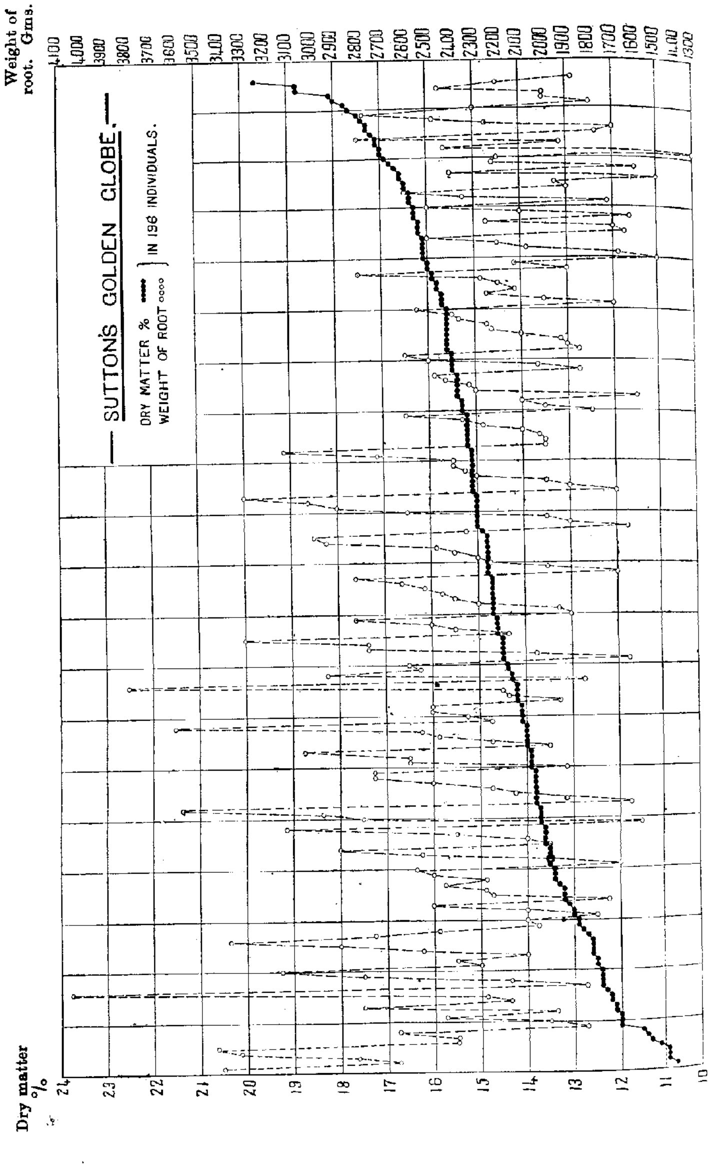
In the meantime we have already made a commencement, and have grown one crop of mangels and one of swedes from seed grown from mother-roots selected for high dry matter. The individuals of this

crop are at present under examination for the selection of mother-roots from which to grow seed for a second selection. The accompanying diagrams (Figs. 7 and 8) show the results of the analyses from which the first selection was made. They are reprinted from our preliminary paper in the *Proceedings of the Cambridge Philosophical Society* already referred to.

The curves in the above diagrams show very great variation in content of dry matter among individual roots of mangels of several strains.

Roots of mangels and swedes selected from the individuals whose composition is given in the diagrams were planted in the spring of 1903, and seed was obtained from them in the autumn of that year. The amount and quality of the seed was, however, very poor, on account of the extreme wetness and coldness of the summer and autumn, and the drought in the spring and early summer of 1904 also militated against the successful germination of what little seed we had to sow. Consequently the crop of 1904 was but a poor one. It is at the present time under examination for the selection of seed-mothers for a second generation.

In conclusion, we desire to express our thanks to Professor Middleton, who has always been ready to help us with advice on all practical points, and has grown material for us on the University Farm; to Messrs Garrett Taylor of Trowse, B. B. Sapwell of Aylsham, Shepherd Cross of Hamels Park, T. Goodchild of Yeldham, B. D. Wood of Field Dalling, E. Druce of the Bedford County Institute, and Major White of Saxlingham, who have grown mangels for us on their farms; to Messrs H. Giles, H. Henshaw, J. Goodchild, B.A., and R. W. B. C. Wood, B.A., who have supervised the sowing, harvesting, and sampling of the roots; and to our senior students, Messrs W. Cartwright, B.A., S. F. Harwood, B.A., and E. F. A. Swann, who have helped us on many occasions when samples arrived faster than we could deal with them. We would also acknowledge our indebtedness to Mr A. D. Hall, M.A., for information about the Rothamsted mangel experiments, to Dr Sigmund Stein for particulars of the sugar-beet industry, and to Mr P. Hedworth Foulkes of the Harper-Adams College for information about the mangel experiments carried out by that institution.


SUTTON'S GOLDEN GLOBE.
DRY MATTER %
WEIGHT OF ROOT
IN 196 INDIVIDUALS.
Weight of root. Gms.
Dry matter %

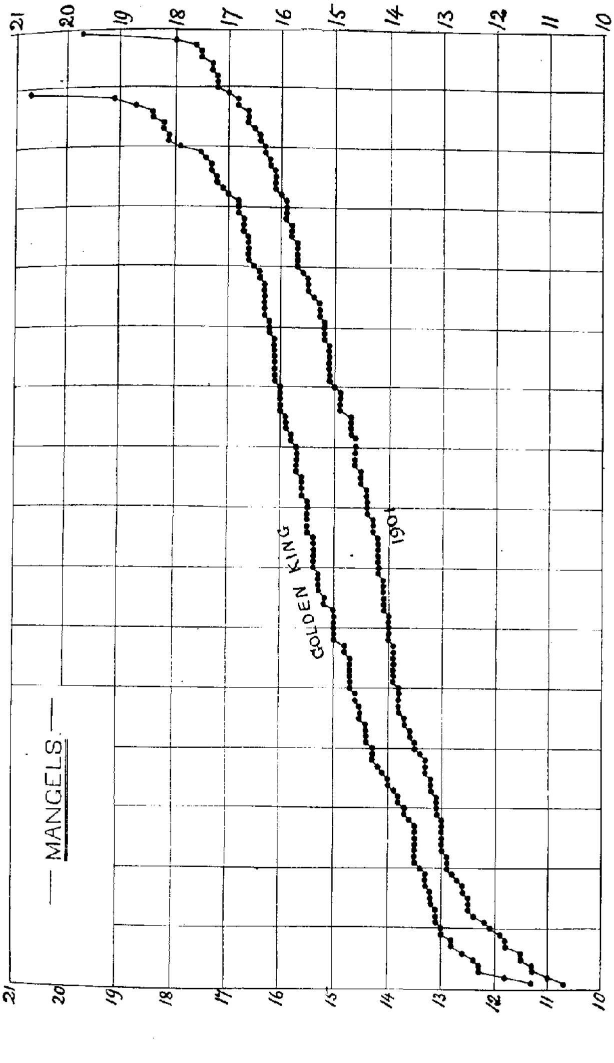


FIG. 8.

Summary.

Below is a brief summary of the chief points of interest which our investigations appear to have suggested so far:

That the most convenient method of sampling roots for analysis is to remove a core from each root, and that when using this method at least 50 roots must be cored in order to obtain a sample representing the composition of the bulk of roots grown on a field.

That a large proportion of the commonly grown strains of mangels may be assigned to one or other of five types.

That of these types, four have their cropping power and percentage of dry matter so nearly in inverse proportion that they yield practically the same weight of dry matter per acre.

That the fifth type, Long Red, yields considerably more dry matter per acre than the other four varieties.

That large roots on the average contain more water and less dry matter than smaller ones.

That there is a considerable variation in the composition of mangels from year to year, probably depending on such conditions as rainfall and sunshine at particular periods of growth.

That manurial treatment causes distinct variations in composition, the most noticeable point being that excessive applications of nitrogen delay ripening and decrease the percentage of dry matter.

That different farms grow roots of different composition.

That there is very great variation among individual roots of the same variety grown side by side, in content of dry matter, sugar, and nitrogen, and in size, shape, colour; in fact, in all the characters which we have been able to observe.

That there is so little correlation between the different characters that it is possible to pick out for seed-mothers large roots containing high percentages of dry matter rich in any desired constituent, and it is suggested that, from analogy with the sugar beet, continuous selection carried out in this manner may result in improvement in any desired direction.

That since colour, shape, and specific gravity of root or of juice are shown not to be correlated with percentage of dry matter, sugar, or nitrogen, selection for these characters is not likely to lead to any improvement.

THE INFLUENCE OF SULPHATES AS MANURE UPON THE YIELD AND FEEDING VALUE OF CROPS.

By T. S. DYMOND, F.I.C., F. HUGHES, and C. W. C. JUPE.

An agricultural problem to which little attention has been directed is the relation of the supply of combined sulphuric acid in the soil to the growth of crops. Field experiments upon the value of gypsum and sulphate of iron have been made, and artificial manures containing sulphates are constantly being used, but the specific effect of the combined sulphuric acid in these materials seems never to have been sufficiently investigated. Indeed, any useful effect produced by gypsum has been ascribed to indirect action, *e.g.*, the liberation of other constituents from insoluble soil compounds.

Yet sulphur is an essential element for plants, and takes as important a position as phosphorus in their quantitative composition. According to published analyses the following crops contain in lbs. per acre:—

	Sulphur	Phosphorus		Sulphur	Phosphorus
Barley.........	6·1	9·0	Vetches	3·9	5·6
Oats...........	8·0	8·4	Beans	9·3	12·7
Maize	3·8	7·9	Swedes	17·8	9·9
Meadow hay	5·7	5·3	Cabbages ..	32·9	25·3
Red clover...	9·4	10·9	Average...	10·8	10·6

The yield of a crop is likely to depend as much upon a sufficiency of available sulphuric acid as upon that of phosphoric acid in the soil, and to constitute a sufficiency, as the foregoing figures shew, more of the former will be often required than of the latter.

There is also another question involved. Sulphur is an invariable constituent of the albuminoids found in crops, and, unless it can be

shown that sulphur can be replaced by oxygen in these compounds, a sufficiency of combined sulphuric acid in the plant food is necessary to the formation of a high percentage of albuminoid. It is therefore not only a question of yield, but also of feeding value. We will first discuss the supply of combined sulphuric acid in the soil and its influence on the yield of crops, and afterwards its relation to feeding value.

In south-east Essex, the existence of sulphates in clay soils is often manifest. On a dry bank under a hedge a white efflorescence of gypsum may frequently be observed. On a bright day after rain the soil of a field will become "capped" with the same substance. In superficial layers of the London clay star-shaped clusters of selenite crystals are often found. Surface-well waters in the same district contain enormous quantities of the sulphates of calcium and magnesium, the latter predominating. One such water from Wickford that we examined had a permanent hardness equal to 93 parts of calcium sulphate per 100,000, and another from Ingrave as much as 112 parts. Rudler suggests that the source of the calcium sulphate is oxidation of the pyrites in the London clay, and reaction of the resulting sulphuric acid with fossils and septaria. It might however be due to the reaction of the sulphuric acid of rain with the calcium carbonate of the surface soil, for the London clay, being almost impermeable, prevents the draining away of the sulphate formed and the solution becomes more concentrated by evaporation. Even a permeable subsoil may contain more combined sulphuric acid than the surface soil. Thus a boulder clay subsoil at Cressing was found to contain 0·055 per cent. sulphuric acid (SO_3), the top soil only 0·028.

A number of Essex soils have been analysed for sulphuric acid. The following table gives the results compared with phosphoric acid, the numbers representing the percentage extracted by strong acid from the fine earth, air-dried, from the top nine inches of soil.

It will be seen that the combined sulphuric acid in Essex soils is very small and is always less than, and averages two-fifths of, the phosphoric acid. It will be suggested that the reason why these soils, though notoriously deficient in phosphoric acid, are not supposed to be deficient in sulphuric acid is that the latter is mostly in an available state. This is not the case; the soil from Gt. Oakley extracted by a one per cent. solution of citric acid gave only 0·006 per cent. "available" sulphuric acid. It must be supposed that the greater part of the sulphuric acid is in the form of insoluble basic sulphates of

aluminium, etc. The small amount of available sulphuric acid in these soils is accounted for by its loss by drainage, sulphates being always one of the most abundant constituents of drainage waters. The sulphuric acid lost by drainage in the 20 inch drain gauge in the Barn Field at Rothamsted was found in 1896 to amount to 71·4 lbs. per acre[1], which would mean a loss to the soil of ·001 per cent.

Percentage of Sulphuric and Phosphoric Acids in Essex Soils.

Locality	Sulphuric Acid. SO_3	Phosphoric Acid. P_2O_5	Locality	Sulphuric Acid. SO_3	Phosphoric Acid. P_2O_5
Birch*	0·038	0·120	Orsett	0·050	0·080
Bromley	0·062	0·250	Great Oakley*	0·048	0·100
Bulphan*	0·030	0·100	Ramsden*	0·080	0·220
Burnham	0·080	0·180	Saffron Walden (1)	0·093	0·110
Cressing	0·028	0·060	,, (2)	0·079	0·090
Dunton*	0·028	0·140	St Osyth	0·043	0·090
Elmstead	0·043	0·080	Tendring (1)	0·035	0·060
Gosfield	0·060	0·240	,, (2)*	0·050	0·160
Margaretting	0·056	0·160	Thaxted (1)	0·040	0·130
Mucking	0·029	0·120	,, (2)	0·045	0·150
North Ockendon	0·039	0·170	AVERAGE	0·051	0·134

* These soils overlie London clay subsoils.

As these analyses point clearly to possible deficiency of sulphuric acid in a state available for crops, some experiments were carried out for the Essex Education Committee in 1896 and the following years upon the specific value of combined sulphuric acid in manures. A difficulty experienced in the experiment was the necessity of eliminating the effect of the base with which the sulphuric acid is combined. On chalky soils the effect of gypsum against no gypsum could be compared, but this was inadmissible on other soils because the lime of the gypsum would exert its own specific physical or chemical influence. On such non-chalky soils sulphate of ammonium as against chloride of ammonium was ultimately used, but the plan is not without objections, for of the sulphuric and hydrochloric acids liberated by nitrification in the soil, the latter will have greater activity in liberating other food materials from feebly soluble compounds owing to its greater ionisation in solution, besides which the formation of calcium and magnesium chlorides, as against sulphates, will render the soil more hygroscopic,

[1] From figures supplied by Mr A. D. Hall.

MANURIAL EXPERIMENTS WITH SULPHATES.

Manures used and Produce in quantities per Acre.

A. With Muriate and Sulphate of Ammonia.

		Muriate of Ammonia, 176 lbs.		Sulphate of Ammonia, 224 lbs.		Increase or Decrease due to Sulphate	
PERMANENT PASTURE—		Hay in cwt.		Hay in cwt.		Hay in cwt.	
At the Hall Farm, Bulphan. Subsoil, London clay. The sulphate and muriate were applied each year. No other manure used. The grass was grazed in 1900.	1896	27·1		25·5		−1·6	
	1897	49·4		51·5		+2·1	
	1898	35·5		31·9		−3·6	
	1899	19·3		18·6		−0·7	
	1901	9·9		13·6		+3·7	
	Mean	28·2		28·2		0·0	
		Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.
OATS— At Frith's Farm, Great Oakley. Subsoil, London clay. Ten loads dung ploughed in just before sowing.	1896	50·4	19·3	45·6	16·3	−4·8	−3·0
BARLEY— On another part of the same field following the oats.	1897	46·3	25·7	44·6	24·4	−1·7	−1·3
CABBAGES—		Tons : cwt.		Tons : cwt.		Tons : cwt.	
At Bearman's Farm, Margaretting. Subsoil, boulder clay. The cabbages were grown on a different field each year, and in each case the land was dressed with dung.	1896	19 : 1·6		20 : 15·5		+1 : 13·9	
	1897	11 : 13·2		12 : 13·5		+1 : 0·3	
	1898	14 : 2·5		14 : 6·7		+0 : 4·2	
	Mean	14 : 12·4		15 : 11·9		+0 : 19·5	

SWEDES—		Tons : cwt.		Tons : cwt.		Tons : cwt.	
At Church Farm, Feering. Subsoil, boulder clay.	1898	5 : 15·4		5 : 11·1		−0 : 4·3	

B. WITH AND WITHOUT SULPHATE OF LIME.

		No Sulphate		Sulphate of Lime 2 cwts.		Increase or Decrease due to Sulphate	
OATS—		Corn and Straw in cwt.		Corn and Straw in cwt.		Corn and Straw in cwt.	
At Lt. Boynton Hall, Roxwell. Subsoil, boulder clay.	1896	32·0		32·1		+0·1	
PEAS—		Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.	Corn in bushels	Straw in cwt.
At Newhouse Farm, Cressing. Subsoil, boulder clay. The peas were dressed with Webb's pea manure containing sulphate.	1896	7·6	...	6·5	...	−1·1	...
At Old Wills Farm, Feering. Subsoil, boulder clay. The peas were dressed with 1¼ cwt. nitrogenous guano (free from sulphate).	1898	34·5	21·8	35·4	22·1	+0·9	+0·3
RED CLOVER—		Hay in cwt.		Hay in cwt.		Hay in cwt.	
At Newhouse Farm, Cressing. Subsoil, boulder clay. The clover was dressed with farmyard manure.	1897	51·7		62·2		+11·5	

and, in dry seasons such as those during which the experiments were carried out, be certain to affect the luxuriance of the crops to some extent.

The results of the experiments are given in the tables[1] on pp. 220 and 221.

These results indicate very clearly the kind of crops that will be increased by the application of combined sulphuric acid in manures, viz. a heavy yielding crop rich in albuminoid. The oats and barley being comparatively poor in albuminoid were not benefited by sulphate manuring, indeed in the case of those grown at Gt. Oakley the chloride had a more beneficial action,—this being due either to its greater activity as a solvent or to its hygroscopic action in the soil during two dry seasons. The swedes, although a crop rich in combined sulphur, are poor in albuminoid, and were not benefited by sulphate manuring, partly however because the yield was so small. Cabbages, a crop which is richer in albuminoid and gives a very heavy yield, were benefited in each of the three seasons the experiment was made. Red clover, also yielding heavily and rich in albuminoid, was increased to the extent of 20 per cent. by sulphate manuring. Permanent pasture gave, on the average of five seasons' crops, precisely the same yield of hay with sulphate as with chloride of ammonium, for neither were the crops heavy nor is the percentage of albuminoid in hay high; but as might have been expected it was found that, in the year that the herbage was analysed (1897), the sulphates had had some influence upon maintaining the clover against the injurious influence of the nitrogen of the manure:—

Clover on the	unmanured plot .	= 32·4	per cent.
„ „	sulphate of ammonium	= 12·6	„
„ „	chloride of ammonium	= 8·6	„

Peas, a crop containing more than an average amount of albuminoid, were slightly benefited when the yield was heavy, but actually injured when the crop was light and an excessive quantity of sulphate employed. That an excessive quantity of sulphate is injurious to crops

[1] For carrying out these experiments the Committee were indebted to Mr Harry Mann, Bulphan, Mr Percy Stanford, Great Oakley, Mr George McMillan, Margaretting, Mr R. W. Christy, Boxwell, Mr J. W. Moss, Feering, Mr Philip Hutley, Witham and Cressing, and Mr J. W. Hepburn. In the tables the names under which the manures are known in commerce are used,—muriate and sulphate of ammonia for ammonium chloride and sulphate, and sulphate of lime for calcium sulphate (gypsum).

seems to be the case, probably owing to its action on the physical condition of the soil. Other field experiments in Essex have shewn the deleterious effect of too large a dressing of superphosphate of lime on mangolds, even on chalky soils, and this is likely to be due to the large quantity of sulphate thus applied. In mixing manures the desirability of limiting the sulphates employed should be remembered, for a mixture of superphosphate, sulphate of ammonia and sulphate of potash, especially when sulphate of lime is added to improve the condition of the manure for sowing, must almost certainly contain an injurious proportion.

As these field experiments demonstrate that the usefulness of sulphate manuring is generally confined to heavy yielding crops containing a high proportion of albuminoid, it remains to be considered why soils so poor in available sulphate still contain sufficient for other crops, whereas the available phosphate is insufficient, although both are required by these crops in nearly equal amount. The two possible sources of supply of sulphuric acid during the growth of a crop are (1) organic sulphur compounds of the soil, and (2) rain. Each of these must be considered.

Berthelot and André[1] have shewn that in addition to the sulphates dissolved by hydrochloric acid and precipitable by barium chloride, sulphur exists in the soil in the form of ethereal sulphates, metallic sulphides, and organic nitrogen compounds of sulphur. The only method of estimating the total sulphur is therefore by combustion, the gaseous products being passed over heated sodium carbonate. By this method they obtained an amount of sulphur nearly eight times as great as that present in the soil in the form of metallic sulphates. This is probably in excess of the proportion found in soils so poor in organic matter as those of Essex; still it is important to enquire to what extent any store of combined sulphur in our own soil can be utilized by oxidation to sulphuric acid.

To investigate this question two glass tubes were filled with a London clay soil (from Birch), both sufficiently moist. Each was sterilized by heating at 100° for an hour and a-half on two consecutive days. One of the two soils was then inoculated with the washings from a little fresh soil. Sterilized air was then passed through each tube for 70 hours at the rate of three litres an hour. Each soil was finally extracted with hydrochloric acid and the sulphuric acid deter-

[1] *Ann. de Chim. et de Phys.* T. 15, p. 119.

mined. The sterile soil was found to contain 0·026 per cent. sulphuric acid, the inoculated soil 0·034 per cent., an increase of 0·008 per cent. by oxidation due to bacterial action[1]. It is therefore clear that the percentage of sulphuric acid extracted from a soil by hydrochloric acid no more represents the supply available for a crop during its whole period of growth, than the percentage of nitric acid represents the available nitrogen.

We turn now to the question of the supply of sulphuric acid in rain. A sample of rain-water collected at this laboratory gave on analysis 1 part of sulphuric acid per 100,000, which for the average annual rainfall between 1895—1903 (= 500,000 gallons per acre) amounts to 50 lbs. per acre, a quantity sufficient for the heaviest crops! But this is greater than that in purely rural districts. The sulphuric acid collected in the small rain gauge at Rothamsted equals 18·5 lbs. per acre[2], a quantity sufficient for cereal crops and permanent pasture, but not for heavy crops of roots or clover. Of course on arable land a considerable part of this will be lost by drainage, but on permanent pasture the quantity is such as to provide for storage of combined sulphur taking place, so that tillage crops may have sulphuric acid produced by the gradual oxidation of the organic compounds stored in previous years when the land was under grass, as well as the sulphuric acid of rain, to depend upon.

Evidence of the sufficiency of the supply of sulphuric acid by rain for most crops, where loss by drainage was prevented, was obtained by a series of pot cultures, the results of which are given in the accompanying table. The sand for the cultures of maize and clover was washed with distilled water till practically free from soluble sulphate. Analysis shewed that it still contained 0·00075 per cent. total sulphuric acid, which amounted to 0·1 gram for the whole pot full of sand (32 lbs.). The sand used in other cultures was probably still more free, as it was first washed with hydrochloric acid and then with distilled water till free from acid. The soils used were obtained from Mucking and from Cressing, and contained 0·028 and 0·029 per cent. of sulphuric acid respectively. Each pot was manured with 5 grams calcium carbonate and 1 gram magnesium carbonate, mixed into the sand or soil, and a solution was applied in small portions from time to time containing 5 grams potassium nitrate and 2 grams

[1] For an account of sulphur bacteria see Conn's *Agricultural Bacteriology*, p. 59.

[2] From figures supplied by Mr A. D. Hall.

of ammonium phosphate. The sulphate pots received 2 grams of gypsum along with the calcium and magnesium carbonate.

Yield of Crops grown in Sand and Soil.

Crop	Grown in	Manured with	Produce as gathered in grams.	Dried at 100° in grams.
Vetches	Sand	Gypsum	38	17*
,, ...	,,	No Gypsum	33	13*
,, ...	Soil	Gypsum	166	30
,, ...	,,	No Gypsum	146	27
Oats (Corn and Straw)...	Sand	Gypsum	11	8
,, ,, ,, ...	,,	No Gypsum	22	13
,, ,, ,, ...	Soil	Gypsum	44	23
,, ,, ,, ...	,,	No Gypsum	51	26
Mustard	Sand	Gypsum	9	5
,, ...	,,	No Gypsum	9	5
,, ...	Soil	Gypsum	28	13
,, ...	,,	No Gypsum	37	18
Onions	Sand	Gypsum	8	†
,, ...	,,	No Gypsum	31	†
,, ...	Soil	Gypsum	285	†
,, ...	,,	No Gypsum	358	†
Maize	Sand	Gypsum	437	73‡
,, ...	,,	No Gypsum	155	22§
Red Clover	,,	Gypsum	49	†
,, ...	,,	No Gypsum	20	†

* Including roots. † Not determined.
‡ Weighed 101 grams, including roots. § Weighed 34 grams, including roots.

While the pots of vetches, oats, mustard, and onions were exposed to rain, the pots of maize and clover were protected. It is in these last two series only that manuring with sulphate produced any visible increase in the crops. Of the other four series, the oats, mustard, and onions, far from being increased by the application of sulphate, were decreased, and of the crops exposed to rain the vetches alone shewed an increase. The reason for this is probably partly due to the vetches being the crops richest in proteids and requiring more sulphur in consequence for development, but chiefly to the injurious effect of the sulphate, in the case of the oats, mustard, and onions, in causing bad physical condition of the sand and soil by "capping" the surface, and thus both limiting aëration and increasing evaporation of water; the vetches, on the other hand, being a covering crop, prevented the capping from taking place. The general result of the pot cultures is

to confirm the lesson of the field experiments, that it is only in the case of heavy yielding crops, rich in albuminoid, that useful results from sulphate manuring can be looked for, and that a large excess of sulphate is injurious owing to physical action on the soil.

Influence on Feeding Value. The object of this part of the investigation was to ascertain whether, since the albuminoid of crops contains sulphur compounds, the proportion of albuminoid, and therefore the feeding value, is increased by manuring with combined sulphuric acid. For the purpose of this enquiry, the pot-grown crops already described, and the grasses and red clover separated from the 1897 herbage of the Bulphan plots were used for analysis, together with some specimens from the experimental plots at Rothamsted kindly supplied by Mr A. D. Hall. Total nitrogen was determined by Kjeldahl's method, albuminoid nitrogen by Stützer's method, and total sulphur by the combustion method (see above). Several duplicate determinations were made, and the authors are satisfied that the analytical methods gave comparable results. The results of the analyses are given in the accompanying table.

The figures shew that manuring with sulphate has always increased the percentage of total sulphur in the crops. In every case but two it also increased the percentage of total nitrogen, and in every case but one the percentage of albuminoid nitrogen. The albuminoid nitrogen per cent. of total nitrogen is sometimes increased, but not always, so that the series appears at first sight to be inconclusive.

But the result of the analyses of the pot-grown crops must be considered in connexion with the yield (see p. 225). In several cases the application of sulphate, by producing an unfavourable condition in the sand or soil, checked plant development. The result would be the increase of the percentage of nitrogen, independently of any absorption of sulphate as plant food, and the probable increase of the percentage of albuminoid owing to the earlier maturity of the crop. Any conclusion must therefore be drawn only from the two pot cultures in which this source of error does not occur, viz. vetches grown in sand and soil and maize grown in sand.

In the case of the vetches, the pots were not protected from rain, and even those not manured with sulphate had therefore a considerable though insufficient supply. That the further application of sulphate increased the percentage of albuminoid as well as the total weight of the crop appears to be conclusive evidence that albuminoid formation is directly dependent on a sufficient supply of sulphate. The increased

absorption and percentage of total nitrogen is the natural result of the formation and storage of albuminoid.

Percentage of Nitrogen and Sulphur in Crops (dried at 100°) grown in sand and soil in Pots and also in the Field.

Crop	Grown in	Manured with	Total S.	Total N.	Alb. N.	Alb. N. % of Total N.
Vetches	Sand	Gypsum	*	3·07	2·27	74
,,	,,	No Gypsum	*	3·00	2·00	67
,,	Soil	Gypsum	0·47	3·41	2·61	76
,,	,,	No Gypsum	0·39	3·16	2·21	70
Oats (Corn & Straw)	Sand	Gypsum	*	0·92	0·50	54
,, ,, ,,	,,	No Gypsum	*	0·87	0·46	53
,, ,, ,,	Soil	Gypsum	0·33	1·50	0·77	51
,, ,, ,,	,,	No Gypsum	0·32	1·47	0·75	51
Mustard	Sand	Gypsum	*	1·55	0·57	37
,,	,,	No Gypsum	*	1·49	0·55	37
,,	Soil	Gypsum	0·63	1·75	0·79	45
,,	,,	No Gypsum	0·50	1·60	0·76	47
Maize	Sand	Gypsum	0·39	1·19	0·98	83
,,	,,	No Gypsum	0·23	2·28	0·83	36
Red Clover	Field	$(NH_4)_2SO_4$	0·36	2·63	1·96	73
,,	,,	NH_4Cl	0·32	2·09	1·79	86
Grass	,,	$(NH_4)_2SO_4$	0·24	1·31	0·98	75
,,	,,	NH_4Cl	0·15	1·06	0·84	79
Wheat (grain)	,,	$(NH_4)_2SO_4$ & NH_4Cl	—	0·91	0·83	91
,, ,,	,,	Rape cake	—	0·89	0·82	92
Barley (grain)	,,	$(NH_4)_2SO_4$ & NH_4Cl	—	0·40	0·32	80
,, ,,	,,	$NaNO_3$	—	0·43	0·37	87

* Quantity of material insufficient for analysis.

In the case of the maize, the crop not receiving sulphate suffered from sulphate starvation to so great an extent that not only the production of albuminoid but also that of carbohydrate was greatly checked. The result was a high percentage of non-albuminoid nitrogen. In the crop receiving sulphate not only was plant development and production of carbohydrate and albuminoid enormously increased, but the percentage of albuminoid and therefore the feeding value was increased also.

By a combination of Stützer's and the combustion methods an attempt was made to determine whether the albuminoid sulphur was proportional to the albuminoid, as otherwise it might be objected that

sulphur not being essential to the composition of albuminoid the formation of albuminoid could not directly depend upon the supply of sulphate. The results were as follows:—

	Sulphate applied.	No sulphate applied.
Total sulphur	0·39	0·23
Albuminoid sulphur	0·15	0·11
Albuminoid nitrogen	0·98	0·82
Ratio $\frac{\text{alb. nitrogen}}{\text{alb. sulphur}}$	6·6	7·5

The two ratios are, within the limits of experimental error, almost in agreement, and at any rate shew that if the sulphur in albuminoid is replaceable by oxygen it is only to a very small extent.

The results of analyses of crops grown in the field do not entirely agree with those of the pot-grown vetches and maize. There is always however the disturbing influence of the substance used on the no-sulphate plot in the attempt to make it comparable with the sulphate plot, an influence which has been accentuated in the Rothamsted crops owing to the same manurial treatment having been extended over a great number of years. These results cannot therefore be held to upset the conclusions arrived at from the pot cultures.

Lastly, the question must be asked as to what are the changes in the percentage composition of a crop, associated with the increase in the percentage of albuminoid. The following analytical results, calculated on dry matter, were obtained.

	Grass from Bulphan		Vetches grown in Sand	
	With Sulphate	Without Sulphate	With Sulphate	Without Sulphate
Albuminoids	6·12	5·25	14·19	12·50
Amides, etc.	2·06	1·37	5·00	6·25
Sol. Carbohydrates	52·09	50·56	50·49	49·47
Fibre	32·40	35·60	25·30	27·10
Oil	1·02	0·92	1·55	1·28
Ash	6·31	6·30	3·47	3·40

These results seem to point to the production of albuminoid being associated with the storage of other reserve material. One of us is preparing to continue the study of this subject from a biological point of view.

To sum up the general conclusions of this enquiry:—

There is not sufficient sulphuric acid in the soil or supplied by rain for heavy yielding crops rich in albuminoid, either for the production of greatest yield or the highest feeding value, and for such crops a sulphate should be included in the artificial manure. For cereal crops and for permanent pasture the soil and rain provide all the sulphuric acid necessary.

COUNTY TECHNICAL LABORATORIES,
CHELMSFORD,
February 4th, 1905.

"BLACK-QUARTER" IN SHEEP.

By T. W. CAVE, F.R.C.V.S.,

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At the beginning of 1902 I was asked to investigate the nature and causation of a disease of sheep, locally termed "struck," with the hope of finding some suitable form of preventive treatment.

I was told that the mortality was very heavy, especially during March, April, and May, and that in one part of the Romney Marsh district a skin dealer had been known to collect 1400 or 1500 skins in a single week, practically the whole of which had been removed from "struck" sheep.

It was further stated as a well-known fact that with many Romney Marsh graziers the losses were equivalent to the death of their entire flocks, once every 16 or 17 years, from this cause alone. The disease was most common in Romney Marsh, but was also met with in other marsh-lands of Kent, and occasionally even in upland districts.

The term "struck" did not convey much meaning to me, a stranger to the locality, but I soon found that, although the term may be applied occasionally to any case of sudden death, yet there was one disease which was chiefly recognized under this name.

Various theories are held by the flock-owners of the district as to the true nature of the disease; some feared an investigation, lest the disease should be declared to be "anthrax," others described it as "acute indigestion" and "hoven," and blamed the young grass of spring-time as the cause. It is also spoken of as "inflammation of the bowels," "apoplexy," &c., but the prevailing opinion seems to be that in some way the new growth of grass in the spring is responsible for the heavy mortality at this period.

The disease certainly is the cause of many deaths in March, April, and May, but sporadic cases occur at all seasons of the year.

Sheep of all ages are attacked, but it is generally said that the best animals in the flock are most likely to suffer.

Soon after my enquiry was begun Mr C. Gillard, M.R.C.V.S., of Ashford, gave me the opportunity of seeing several cases in in-lamb ewes which were said to be "struck." As the outbreak proved to be of a severe character, 60 ewes dying in a few weeks out of a flock of 200, a carcase was sent by Mr Gillard to Professor M'Fadyean, who declared that death was due to "black-quarter."

This outbreak occurred in a district at some elevation above sea-level, where the loss from "struck" sheep was said to be usually slight.

As it had been known for many years that sheep suffered from "black-quarter" in some parts of Great Britain (Steel's *Diseases of Sheep*), I determined to find out whether sheep in Romney Marsh, which were said to be "struck," showed any of the lesions of that disease.

On post-mortem examination of a "struck" sheep it is usual to find some portion of the body greatly swollen, and the skin of a dark purple colour. Well-marked crepitations are discovered on palpation of the swellings. The swellings are frequently found on the inside of the hind-limb, extending from the hock to the groin and even along the abdominal wall; in the fore-limb extending from the knee upwards to the shoulder, and the muscles of the neck and back.

On removal of the skin the swollen parts are seen to be black or dark red in colour, and the subcutaneous connective tissue and the muscles are saturated with a blood-stained fluid which rapidly drains away when an incision is made.

Bubbles of gas escape from the surface of the section, and a well-marked odour of sour milk is easily distinguished.

In the internal organs the chief lesions are congestion of the lungs and the presence of bloody serum in the pleural and peritoneal cavities. These lesions seem to be identical with those of "black-quarter."

On making a microscopical examination of the fluid squeezed from the diseased flesh numerous rod-like organisms with rounded ends are to be found. These bacilli closely resemble those of "black-quarter." They are also to be found in the blood and in the pleural and peritoneal fluids.

A "struck" sheep rarely shows signs of ill-health. Generally the sheep is found dead in the pasture, although it may have been seen

apparently in good health a short time earlier. Sometimes the animal is seen to stagger, to fall to the ground, and to die in a few minutes.

More rarely death is delayed for some hours, and the sheep is seen standing with its four feet close together, its back arched, and breathing rapidly. There may be a frothy, blood-stained discharge from the nostrils, and a blood-stained diarrhœa. The animal moves unwillingly, and when made to do so exhibits considerable stiffness of the limbs. Soon it falls to the ground and quickly dies.

Owing to the rapid onset of the disease and the suddenness of death it is very difficult to say whether any marked swellings are to be detected during life. The thickness of the wool also makes the detection of the swellings more difficult while the animal is alive.

I rarely had the opportunity of examining a "struck" sheep during life, but I was able to make a considerable number of post-mortem examinations, and I always found swellings present in some part of the body, and the bacilli of "black-quarter" were always present in the exudate from the diseased muscle.

As it was not possible for me to make a bacteriological examination at the College, I submitted a slide of the bacilli to Professor M'Fadyean, who identified the organism as the "bacillus of black-quarter."

At a later stage of the enquiry Dr Hamilton, of Aberdeen, visited Romney Marsh with me and examined several carcases of "struck" sheep, and afterwards made a careful bacteriological examination of fluids and tissues then obtained. He informed me that he "found a bacillus quite comparable with that of 'black-quarter,' although he was not as yet prepared to say that they were identical."

I also learned that some years ago the late Mr Alston Edgar, F.R.C.V.S., of Dartford, Kent, had declared that "struck" sheep died from "black-quarter."

In order to prove to the sheep-owners of the district that the disease was not due to any dietetic cause as was popularly supposed, I inoculated a healthy sheep with the serum obtained from the diseased muscle of a "struck" sheep. The fluid was injected deeply into the muscles of the thigh, and the sheep died within 12 to 14 hours after the inoculation. The inoculated sheep presented all the appearances of a "struck" sheep, and a microscopical examination of the exudate showed the presence of numerous bacilli of "black-quarter."

The conclusions I drew from my enquiry were that the term "struck" was chiefly used in reference to sheep which after death presented the lesions above described, that these lesions were identical

with those of "black-quarter" in cattle and sheep, that the "black-quarter" bacillus was invariably present, and that practically the whole of the annual loss from "struck" sheep was due to the presence of the bacillus of "black-quarter."

This bacillus is known to exist in the soil of certain pastures, usually in damp, low-lying situations. Its spores are most tenacious of life. They will resist heat and cold, dryness and moisture, and may remain dormant in the soil for many years.

It is probable that infection occurs through the digestive-organs, but it has also been suggested that the spores may enter the body through small punctured wounds[1].

PREVENTIVE MEASURES SUGGESTED.

As soon as I became aware that the disease was identical with "black-quarter" in sheep, I endeavoured to find some means of prevention suitable to the districts in which heavy losses occurred annually.

First, it was pointed out that the usual method of dealing with the carcase of a "struck" sheep was conducive to the prevalence of "black-quarter."

Throughout the Romney Marsh district carcases are flayed and then allowed to lie unburied, to be gradually destroyed by decomposition, or to be eaten by dogs, poultry, rats, &c. In this way the organisms contained by the diseased carcases are allowed to return to the soil, where the spores may live for many years, retaining their power to produce "black-quarter" when again introduced into the body of a living sheep.

Much benefit might be derived in a few years from the general and uniform adoption of some plan for the total destruction of *unflayed* carcases. Cremation would, of course, be the ideal method to be adopted, but the expense of burning a large number of carcases during the spring months would be considerable, and could only be met by the co-operation of a number of sheep-owners. If small kilns or destructors could be erected in suitable situations, arrangements might be made for working them more economically than would be possible for the individual owner. Failing cremation, the carcases should be buried deeply in the ground where practicable; when the character of the soil prevents any but shallow graves being dug, then plots of ground should be fenced off and used only for burial purposes, as suggested by Dr Hamilton for cases of "braxy."

[1] *Annual Report of the Bureau of Animal Industry, U.S.A., for* 1898.

It is certain that the total destruction of unflayed carcases would ultimately bring about a gradual decrease in the number of cases.

Second, an attempt was next made to show whether protective inoculation against "black-quarter" in sheep was of any value. As is well known, considerable success has attended the adoption of protective inoculation of young cattle against "black-quarter," both in this country and abroad. Mr Gilruth, M.R.C.V.S., the chief veterinarian and bacteriologist to the New Zealand Government, recently reported that in one district alone 2250 calves have been vaccinated as a preventive measure, with a subsequent loss of only two animals. He also mentions that in a district where "black-quarter" is very rife, "if done twice a year vaccination is a great success[1]."

I hoped to find that protective inoculation of sheep would prove equally valuable. Unfortunately, I was unable to obtain any vaccines especially prepared for sheep, and I was obliged to try those used for cattle. These vaccines were of the usual type—virulent muscle, dried and attenuated by heat, and then reduced to a powder.

During 1903 I used three vaccines:

A. A double vaccine (English).

B. A single vaccine (foreign).

C. The first dose of the double vaccine *A* used as a single vaccine.

As will be shown later, none of these vaccines proved quite satisfactory, and, as they were kindly given to me for trial, I have not made known their origin.

In the spring of 1903 I vaccinated a small number of sheep at the College Farm with the vaccines *A* and *B*, chiefly with the object of finding which was the most suitable part of the body for the purpose. In some the interdigital space of a forefoot was selected as the seat of the inoculation, in others the inside of the thigh or the axilla. In all cases the skin was first scrubbed with a 2 per cent. solution of lysol.

When the double vaccine was used the first dose was given in a right limb, the second eight days later in a left limb. None of the sheep suffered any inconvenience from the injections, whether given in the feet, or under the skin of the thigh or of the axilla. As the inside of the thigh was found to be the most convenient situation for the injection, it was generally selected in the later experiments.

[1] *Report of the Division of Veterinary Science of the New Zealand Department of Agriculture*, 1904.

From this lot of vaccinated sheep I then selected two, one twice vaccinated with *A*, the other vaccinated with *B*. A third sheep, which was unvaccinated, was used as a control animal. All three were inoculated with virulent "black-quarter" muscle injected deeply into the muscles of the thigh, each animal receiving exactly the same dose. Within 24 hours the unvaccinated sheep and one of the vaccinated (single *B*) sheep were dead, while the third sheep, which had been twice vaccinated (double vaccine *A*) remained unaffected by the dose of virulent muscle it had received. The two sheep which died presented the usual appearance of badly "struck" sheep. The doubly vaccinated sheep was lame for some days owing to the pain caused by the puncture, but no symptoms of "black-quarter" were developed.

From this result I concluded that the double vaccine would prove most efficient in giving immunity against the naturally acquired disease.

In the summer of 1903 I arranged with a number of sheep-owners to vaccinate small lots of sheep in various parts of Romney Marsh during the following winter.

As I fully anticipated the possibility of some slight loss resulting from the inoculations, it was arranged that compensation should be paid for any sheep which died from the action of the vaccine.

Judging from the risks met with in the vaccination of cattle I had no reason to expect that the loss in sheep would be more than 1 or 2 per cent., but of the 308 sheep vaccinated during October, November, and December, 14 died within a few days, and the deaths were evidently due to the vaccination, making a loss equal to 4½ per cent.

Of the 14 deaths only one was due to the foreign vaccine *B*; the remaining 13 deaths were caused by the English vaccines *A* and *C*.

Table I shows the loss caused by each of the three vaccines:

An examination of this table shows that:

1. The foreign vaccine *B* was used on 218 sheep with the loss of one only, or less than ½ per cent. Vaccine *B* may therefore be regarded as practically free from risk when used on sheep.

2. The double vaccine *A* caused a loss of 11 sheep out of 80 vaccinated, or nearly 14 per cent. Of the 11 deaths, one was caused by the first dose, 10 by the second. The deaths were directly due to the vaccination, occurring about 48 hours after the operation. The lesions of "black-quarter" were well marked, and were localized at the seat of the inoculation.

3. The single vaccine *C* was only tried on 10 sheep with a loss of two, or equal to 20 per cent.

The loss of 11 sheep caused by the double vaccine *A* was most

unfortunate, as it compelled me to abandon its use, although I had already shown that a high degree of immunity was to be expected when it was tried on an extensive scale. It is of course possible that had a large number of sheep been vaccinated with *A* the percentage of loss would have been greatly reduced, but I was not in a position to risk any further loss, and was obliged to be satisfied with the small number of sheep (69) which had passed safely through the inoculations.

TABLE I.

DEATHS DUE TO VACCINATION.

Owner	No. of Sheep Vaccinated	Deaths due to Vaccination	
	THE DOUBLE VACCINE (A)		
Mr E. Lord	30	1	(2nd dose)
Mr A. Finn	50	10	(1 due to 1st dose, 9 due to 2nd dose)
Total	80	11	total loss (nearly 14 per cent.)
	THE SINGLE VACCINE (B)		
Mr E. Lord	40	0	
Mr A. Finn	40	0	
Mr L. J. Pankhurst	20	0	
Mr T. J. Pearson...	49	0	
Mr Geo. Neve	69	1	
Total	218	1	total loss (less than ½ per cent.)
	THE SINGLE VACCINE (C)		
Mr T. J. Pearson...	10	2	(loss 20 per cent.)

This vaccine had been used on a small number of sheep with perfect safety at the College Farm in the spring, but when used in October in Romney Marsh the result was disastrous, 11 sheep out of 80 being killed by it. In the spring the sheep used in the experiment were well protected from bad weather during the critical period following the inoculations. In October the sheep used in the experiment were living in the open, and were exposed to adverse climatic conditions.

It seems possible that exposure to bad weather during the 48 hours following the inoculations may be a cause of loss. Anything which would lower the vitality of the sheep might give the organisms contained

in the vaccine the upper hand, and allow them to produce the actual disease instead of merely rendering the animals immune. This theory is supported to some extent by what occurred in connection with the loss of nine sheep due to the second dose of vaccine *A*.

Two lots of sheep in different parts of Romney Marsh were given the second dose of vaccine *A* on the same day, the same dose being used for all the sheep.

In one lot not a single sheep suffered any inconvenience, in the other nine sheep died from the inoculations during the next three days.

For the 48 hours following the inoculation of the two batches of sheep the weather was most unfavourable, for a strong south-westerly gale was blowing, with heavy rainstorms. The sheep in which the loss occurred were near the coast, and were absolutely without shelter, exposed to the full force of the gale. The other lot, in which no deaths occurred, were several miles further inland and in a much less exposed situation, some shelter being provided by trees, hedges, buildings, &c.

Later, the first dose of the double vaccine *A* was tried on 10 sheep as the single vaccine *C*, but in a reduced dose. Two out of the 10 sheep died within 48 hours. On enquiry it was found that the weather had again proved unfortunate during the critical period, the nights being very cold with sharp frost[1]. It should be mentioned that before this loss occurred altogether 90 sheep had been given the first dose of vaccine *A* with the loss of one sheep only, yet a reduced dose used in cold weather caused the loss of two out of 10 sheep.

The sheep which had passed safely through the vaccination, together with a number of unvaccinated sheep, were pastured on land well known to be dangerous. The whole of the sheep, about 550 in number, were kept on the dangerous pastures until June, 1904, and careful records were kept of the number of "struck" sheep in the two classes.

From these records the following tables were prepared, showing the number of sheep which were "struck" up to the conclusion of the experiment. It was impossible for me to examine all the sheep which were "struck," but from time to time samples of diseased muscle were sent to me for examination, and in these I was able to detect the presence of the "black-quarter" bacillus.

In the tables below the losses in "struck" sheep in vaccinated and unvaccinated animals have been compared by reducing the figures to a percentage, but of course with such small numbers percentages are

[1] It is interesting to note that sheep owners insist that more sheep are "struck" on frosty nights in spring than at any other time.

not altogether satisfactory. Very different results might be obtained even with the same vaccines if used on a much greater number of animals.

TABLE II.

THE DOUBLE VACCINE *A*.

Time of Vaccination	Owner	No. of sheep vaccinated	No. of sheep "struck"	Percentage of loss in vaccinated sheep	No. of unvaccinated sheep	No. of sheep "struck"	Percentage of loss in unvaccinated sheep
October, 1903 ...	Mr E. Lord, jun.	29	0	0	111	2	1·80
October, 1903 ...	Mr A. Finn	40	1	2½	50	9	18
		69	1	1·44	161	11	6·83

TABLE III.

THE SINGLE VACCINE *B*.

Time of Vaccination	Owner	No. of sheep vaccinated	No. of sheep "struck"	Percentage of loss in vaccinated sheep	No. of unvaccinated sheep	No. of sheep "struck"	Percentage of loss in unvaccinated sheep
October, 1903...	Mr Lord............	40	0	0	111	2	1·8
October, 1903...	Mr Finn............	40	8	20	10	1	10
November, 1903	Mr T. J. Pearson	49	2	4	51	2	4
November, 1903	Mr Pankhurst ...	20	1	5	20	2	10
December, 1903	Mr Neve............	68	3	4·4	65	6	9·2
		217	14	6·45	257	13	5·05

TABLE IV.

THE SINGLE VACCINE *C*.

Time of Vaccination	Owner	No. of sheep vaccinated	No. of sheep "struck"	Percentage of loss in vaccinated sheep	No. of unvaccinated sheep	No. of sheep "struck"	Percentage of loss in unvaccinated sheep
November, 1903	Mr Pearson	8	1	12½	51	2	4

These tables show very clearly the success or non-success of the vaccines in securing immunity.

TABLE II.

Of the 69 vaccinated sheep only one was "struck," equal to a loss of 1·44 per cent., while of the 161 unvaccinated sheep 11 were "struck," equal to a loss of 6·83 per cent.

But the most remarkable result was obtained in the sheep owned by Mr A. Finn, of Lydd. These sheep, 90 in number, were kept from October, 1903, to June, 1904, on a particularly dangerous pasture at Broomhill.

Mr Finn states that during his occupation of this land he has had 16 to 20 per cent. of sheep "struck" annually.

Out of the 40 vaccinated sheep only one was "struck," or a loss of 2½ per cent., while of the 50 unvaccinated sheep nine were "struck," making a loss of 18 per cent.

It has already been shown that a high degree of immunity can be produced in sheep by the use of this double vaccine—a vaccinated sheep has resisted the introduction of a known quantity of highly virulent material which was capable of killing two control animals in 24 hours. It seems therefore reasonable to assume that the remarkable contrast between the number of sheep "struck" in the vaccinated and unvaccinated animals is due to the effect of the double vaccine *A* which rendered the 40 sheep strongly immune against "black-quarter" and consequently only one was "struck."

It is possible that the suggestion may be made that this result was due to the fact that all susceptible animals were killed off by the doses of vaccine and that the remaining sheep were naturally immune against the disease. Such an objection might equally be made where cattle are vaccinated against "black-quarter" or where cattle and sheep are vaccinated against "anthrax," and it would be difficult to refute the suggestion except by the comparison of losses in very large numbers of vaccinated and unvaccinated animals.

TABLE III.

Of the 217 vaccinated sheep 14 were "struck," a loss equal to 6·45 per cent., while of the 257 unvaccinated sheep 13 were "struck," or a loss equal to 5·05 per cent.

The single vaccine *B* has failed to protect sheep against "black-quarter," but it is possible that different results might be obtained if this vaccine were used nearer to the dangerous spring season. An examination of the table shows that Mr Neve's sheep, vaccinated at the end of December, 1903, seem to have had a slight degree of immunity. Of the 68 vaccinated sheep three were "struck," equal to a loss of 4·4 per cent., while of the 65 unvaccinated sheep six were "struck," making a loss equal to 9·2 per cent. The annual loss on this land was said to be 9 per cent.

TABLE IV.

The single vaccine *C* caused the loss of two sheep out of 10, and its use was abandoned. Of the eight sheep remaining one was afterwards "struck," so that this vaccine was powerful enough to kill and yet failed to give a strong immunity.

The conclusions which may be drawn from these attempts to immunise sheep against "black-quarter" are:

1. That the double vaccine *A* undoubtedly renders sheep strongly immune against "black-quarter."

2. That the double vaccine *A* is uncertain in its action, and under certain conditions may be highly dangerous when used in the field.

3. That a single vaccine may be powerful enough to kill and may yet fail to give a lasting immunity to those animals which survive the inoculations.

4. That none of the vaccines tried in these experiments have proved entirely satisfactory, although enough has been done to show that the loss from "struck" sheep could be greatly diminished by protective inoculation, if a safe and efficient vaccine were available.

It is possible that more favourable results will be obtained in the future by the use of vaccines specially prepared for sheep. Experiments are now being conducted on these lines and the results will be communicated on their completion.

ON THE ACCUMULATION OF FERTILITY BY LAND ALLOWED TO RUN WILD.

By A. D. HALL,

Director of the Rothamsted Experimental Station
(Lawes Agricultural Trust).

It is well known that the fertility of "virgin" soils is due to the accumulation of the *débris* of a natural vegetation which has been in occupation of the soil for a long epoch previously. Only when the climate and rainfall are suitable to the growth of the plants and the partial preservation of their residues does a virgin soil of any richness arise; on the one hand, virgin soil may be as poverty stricken as the most worn-out European field because it has never carried any vegetation; on the other hand, as in the tropics, the *débris* of an extensive vegetation may decay with such rapidity that no reserve of fertility accumulates. In temperate climates, and with a particular distribution of the annual rainfall, occur the grassy treeless prairies and steppes which provide the ideal conditions for the accumulation of fertility. But that fertility does increase when land is in the state of permanent grass has long been an axiom in our farming; the results set out below will serve to show at what rate the increase takes place under prairie conditions in this country, *i.e.* when the land is left absolutely to itself and not even grazed by stock.

In 1882 about an acre of the upper end of the Broadbalk field at Rothamsted, which had then been carrying wheat for forty years in succession, was not harvested, the crop was allowed to stand and shed its seed without cultivation of any kind. In the following season a fair quantity of wheat came up on this part of the field, but gradually got weaker as the season advanced and the weeds increased their hold on the land. The wheat was still left to struggle on without cultivation, and by the fourth season only three or four stunted plants

could be found, each carrying but one or two grains in the ear. With these the wheat disappeared and has never been seen again in that part of the field. This illustrates the fact that our farm crops have become so specialised that they are unable to exist in competition with weeds and other natural vegetation, and are entirely dependent on cultivation to relieve them from that competition. The piece of land in question has been left untouched since that time, and has covered itself with a coarse grassy herbage interspersed with thorn bushes and briars, young oaks, and other shrubs of the district. Before, however, these shrubs could meet and establish a continuous covert they were stubbed from one portion so as to leave the herbaceous and grassy vegetation only in possession. This piece of land now represents the result of something more than 20 years of prairie conditions in England, and as samples of soil had been taken at starting it affords an opportunity of gauging the rate at which fertility is accumulating. A very similar experiment was also made with a portion of the Geescroft field, which had carried beans from 1847 to 1878 and clover from 1883 to 1885; after the second cutting of clover in 1885 the field was fenced off and has been left untouched ever since.

The fate of these two pieces of waste land was a matter of great interest to the late Sir John Lawes, he constantly referred to them, and in 1895 wrote a suggestive little paper on them and on the vegetation they then carried in the *Agricultural Students' Gazette* (R. Ag. Coll. Cirencester, 1895, p. 65). In this paper Sir John Lawes discussed the probable character of the Rothamsted soil when it was in its "virgin" condition, and the exhaustion it may be supposed to have suffered during its many centuries under arable cultivation.

Table I shows the carbon and nitrogen in the soil at the beginning of the experiment and in 1904. Both fields show a marked gain of carbon and nitrogen down to the third depth of 27 inches, the increase in the lower depths being due to the roots which have decayed in that stratum. It is difficult to convert these percentages into actual quantities per acre, owing to the uncertainty which must exist as to the layer of soil which is under examination. The sampling tool is driven down each time to the depth of nine inches, but the evidence points to a much more consolidated state of the soil in 1882, when it had been under arable cultivation with artificial manures alone for forty years, than in 1904 when it had long been in grass. Consequently the successive layers taken by the tool in 1904 are lighter than they were in 1882, they are essentially a little thinner

since the soil has been, as it were, expanded in the interval by the accumulation of organic matter. But because the organic matter decreases as one gets lower in the soil, the thinner slices of the later samples exaggerate the percentage of organic matter in the soil. It is almost impossible to introduce a correction except by taking such a large number of soil samples that the error in calculating from a sample six inches square the weight of soil per acre is

TABLE I.

Accumulation of Carbon and Nitrogen in Soil of Land allowed to run wild for more than 20 years.

	Per cent. in Dry Soil			
	Carbon		Nitrogen	
	1881–3*	1904	1881–3*	1904
Broadbalk, 1st 9 inches......	1·143	1·233	0·1082	0·1450
,, 2nd 9 ,, ...	0·624	0·703	0·0701	0·0955
,, 3rd 9 ,, ...	0·461	0·551	0·0581	0·0839
Geescroft, 1st 9 inches......	1·111	1·494	0·1081	0·1310
,, 2nd 9 ,, ...	0·600	0·627	0·0739	0·0829
,, 3rd 9 ,, ...	0·447	0·438	0·0597	0·0652

* Broadbalk, 1881; Geescroft, 1883.

eliminated. If the total amounts of nitrogen in the Broadbalk soils be calculated on the assumption that the weights of the soil layers were the same in 1904 as in 1882, the total gain of nitrogen per acre would amount to 2200 lbs., which is at the rate of more than 100 lbs. per acre per annum. So great an accumulation of nitrogen is manifestly impossible to account for in the present state of our knowledge, and as the introduction of any allowance for the lightening of the soil would be a very speculative proceeding, it is better to let the results stand for the present as only comparable with the similar results obtained on the Geescroft field. The Geescroft field shows

a similar though smaller increase in the proportion of carbon and nitrogen down to the depth of 27 inches; considering the surface soil only the difference in the amount of nitrogen accumulated by the two fields amounts to about 350 lbs. per acre. The fact that the increase on Geescroft is smaller than on Broadbalk is of considerable interest, because after the Geescroft sample had been taken in 1883 clover was grown for three years before the land was allowed to run wild. Moreover the soil was sampled again in 1885, after three years' growth of clover, and showed in the surface soil an increase of nitrogen, which then amounted to 0·1152 °/$_o$ instead of 0·1081 °/$_o$ in 1883. The Geescroft field had in fact some start of the Broadbalk field, why did it not maintain its lead? The answer is probably to be found in the botanical composition of the wild herbage which has taken possession of these two bits of waste.

It should be remembered that previously the Broadbalk land had been growing wheat, the Geescroft field beans until they would grow no longer, then a good crop of clover. At the present time the vegetation on the Broadbalk waste contains a fair proportion of leguminous plants, chiefly meadow vetchling, while this class of plants is and has been for many years, since the dying out of the clover, absent from the Geescroft waste. It is impossible to refrain from correlating the absence of leguminous herbage on these old bean and clover plots with the well-known fact that land becomes "sick" of the leguminous crops in a way that never happens with the other farm crops. As Sir John Lawes pointed out in the paper already referred to, the Black Medick is a persistent weed in the Rotation field on the plots which are bare fallowed, but not on the plots which grow clover or beans once every four years. Further, the absence of leguminous herbage collecting nitrogen from the atmosphere would explain why the Geescroft field has gained nitrogen less rapidly than has the Broadbalk field with its more mixed herbage.

Another question however arises; how comes it that the Geescroft land, with no plants growing on it which are capable of fixing free nitrogen, has yet gained an enormous quantity of nitrogen during the twenty years under review, a quantity which at the lowest reckoning amounts to about 25 lbs. per acre per year? The nitrogen brought down in the rain would account for perhaps 5 lbs. per acre per annum, a little more will come in the form of dust, bird-droppings, and other casual increments, while some may be due to fixation of atmospheric nitrogen by bacteria in the soil not associated with leguminous plants,

like the *Azotobacter chroococcum* of Beyerinck and Winogradsky's *Clostridium Pastorianum*. The *Azotobacter* has been found abundantly in the Rothamsted soils, and as in the case of grass land like the present the decaying vegetation would supply the carbohydrate which the bacterium must oxidise in order to fix nitrogen, it is quite possible that it may have effected considerable gains of nitrogen. Two other causes may be at work, the absorption of atmospheric ammonia by soil and plant, and the rise of nitrates from the subsoil. To what extent the traces of ammonia in the atmosphere are absorbed by the soil, as distinct from the washing down of ammonia by the rain, is still a matter of uncertainty, the investigations of Kellner and of Schloesing indicate a comparatively high figure, about 40 lbs. per acre per annum as a maximum. But a gain of nitrogen from this source should be even more in evidence on the arable than on grass land, yet the unmanured plots on the arable land do not show any similar amounts of nitrogen either in soil or in crop. Again, though practically no nitrates are found in the drainage water immediately below grass land, both because nitrification is slow and the living plant is active in taking up the nitrates as fast as they are formed, yet nitrates are comparatively abundant in the permanent subsoil water. No data exist on the subject, but it is not unreasonable to suppose a certain amount of capillary creep of these nitrates up to the zone where the surface vegetation could reach them. Only by the capillary movements of subsoil nitrates, laterally or vertically, can one understand how trees in many places continue to obtain the requisite nitrogen for their yearly increase. However, from one cause or other, this Geescroft field during its twenty years of lying in rough natural vegetation does show an increase in fertility which is not entirely easy to account for on ordinary lines.

The contrast between the vegetation of the two plots is very considerable, and as a complete botanical separation was made of portions cut in 1903, the amounts contributed by the chief species are set out in Table II.

It will be seen that not only is the Geescroft herbage practically without leguminous plants, but it consists almost wholly of a single grass, *Aira cæspitosa*, which occurs to but an inappreciable extent on Broadbalk, where the herbage is of a much more general nature.

It is difficult to account for the extraordinary differences in the herbage of these two pieces of land; the two fields are not far apart, and, as the mechanical analyses given in Table III show, the soils are of very similar physical structure.

TABLE II.

Composition of Herbage on Land that has run wild for more than 20 years. June, 1903.

	Broadbalk	Geescroft	
GRAMINEOUS HERBAGE			
Number of Species	11	10	
Botanical Names:—	Per cent.	Per cent.	
Gramineæ 1. Phleum pratense	4·89	0·08	Catstail
Gramineæ 2. Agrostis alba	11·02	0·20	Common Bent
Gramineæ 3. Aira cæspitosa	—	86·19	Tufted Hair-grass
Gramineæ 4. Arrhenatherum avenaceum	3·50	2·34	False Oat-grass
Gramineæ 5. Dactylis glomerata	35·12	4·53	Cocksfoot
Gramineæ 6. Lolium perenne	3·22	0·05	Perennial Rye-grass
Other species amounting to	1·89	1·87	
Total	59·64	95·26	
LEGUMINOUS HERBAGE			
Number of Species	5	2	
Leguminosæ 1. Trifolium repens	3·08	0·05	White or Dutch Clover
Leguminosæ 2. Trifolium pratense	0·55	—	Common Red Clover
Leguminosæ 3. Vicia sepium	0·40	0·38	Bush Vetch
Leguminosæ 4. Medicago lupulina	2·92	—	Black Medick
Leguminosæ 5. Lathyrus pratensis	18·36	—	Meadow Vetchling
Total	25·31	0·43	
MISCELLANEOUS HERBAGE			
Number of Species	24	14	
Umbelliferæ 1. Heracleum sphondylium	4·28	1·71	Cow Parsnip or Hogweed
Dipsaceæ 2. Scabiosa arvensis	2·87	—	Field Scabious
Compositæ 3. Centaurea nigra	1·05	—	Black Knapweed
Compositæ 4. Carduus arvensis	0·81	0·30	Creeping Plume Thistle
Plantagineæ 5. Plantago lanceolata	2·46	0·26	Ribwort Plantain
Polygonaceæ 6. Rumex obtusifolius	—	0·94	Broad-leaved Dock
Other species amounting to	3·58	1·10	
Total	15·05	4·31	
SUMMARY			
Gramineæ	59·64	95·26	
Leguminosæ	25·31	0·43	
Miscellaneous species	15·05	4·31	
Total	100·00	100·00	

TABLE III.

Mechanical Analysis of Soil with wild Vegetation.
Rothamsted, 1904.

Percentages dried at 100° C.

	Soil to 9″		Subsoil 10—18″	
	Broadbalk	Geescroft	Broadbalk	Geescroft
Fine Gravel, 3 to 1 mm.	1·88	2·05	1·14	2·33
Grit, 1 to 2 mm.	6·15	5·13	3·16	3·19
1st Sediment, 0·2 to 0·04 mm.	22·95	27·88	11·86	17·69
2nd Sediment, 0·04 to 0·01 mm.	25·32	25·65	14·63	24·83
3rd Sediment, 0·001 to 0·004 mm.	7·98	7·17	5·56	7·14
4th Sediment, 0·004 to 0·002 mm.	4·02	4·09	4·14	3·85
Klay, below 0·002 mm.	21·17	23·49	50·88	29·55
Loss on solution and moisture	9·0	3·87	8·46	5·85
Total...	98·47	99·33	99·83	94·43

Despite the identity of the mechanical composition of the two soils, the Geescroft field when under arable cultivation had always the reputation of being the wettest and most unworkable field on the farm. During the earlier years of the Rothamsted experiments both oats and beans were grown upon this field, yet it was found impossible to continue the trials, so frequent were the failures to obtain a plant through the intractable nature of the ground in a wet season. Where nitrate of soda was used the land became specially difficult to manage, remaining persistently wet and then drying with an excessively hard crust. For example, we read that in 1877 the land could not be worked in time for sowing oats; the last crop was in 1878, "since which, owing to the wetness and foulness of the land for several years, it was left fallow." On the same field again, during the eleven years, 1871–81, it was only possible to obtain four crops of beans, so wet was the land. Even at the present time water may often be seen standing on this field, although it is practically at the highest part of the farm, and there is nothing in its surroundings to lead surface water towards it. It is true that it is not underdrained as the Broadbalk field is, but on none of the Rothamsted land would tile drainage be usually considered necessary, for the soil is lighter than a true clay

and the porous chalk lies only a few feet below. The mechanical analysis indeed indicates a lighter subsoil for Geescroft than for Broadbalk, and this is borne out by the existence of pits, from which sand is won, not very far from the Geescroft field. The vital difference to be found in the soil of the two fields is the presence of chalk in the surface soil of Broadbalk and its absence in the Geescroft soil. The soil of the Rothamsted estate contains naturally no carbonate of lime, but during the eighteenth century most of the arable fields were heavily chalked by the simple process of sinking a pit through the clay to the chalk rock below, which was then drawn out and spread on the land. Thanks to this the Broadbalk field contains to-day about 3 per cent. of chalk in its surface soil, though little or none is present in the lower layers; the Hoos field contains about 2 per cent., Barnfield about the same, while some parts of Agdell field contain as much as 5 per cent. Now the Geescroft field contains about the same proportion as is to be found in the natural uncultivated soil from the adjoining Harpenden Common, a little more than one-tenth per cent. of carbonate of lime, so that evidently it must have escaped the chalking processes, which were already dying out when Sir John Lawes came into possession in 1835. Table IV shows the amount of Calcium Carbonate in the first and second nine inches of the soils of these two fields and

TABLE IV.

Calcium Carbonate in Rothamsted Soils, 1904

Percentages in Soil dried at 100°.

	Broadbalk	Geescroft	Harpenden Common
1st depth 0—9″	3·325	0·160	0·210
2nd depth 10—18″ ...	0·126	0·131	0·136

of the uncultivated Harpenden Common. It is impossible to resist the conclusion that the unworkability of Geescroft, which practically caused its abandonment as an experimental field and indeed as arable land at all, and the extraordinary differences to be seen in the natural herbage it now carries, are due to the lack of the chalking received by the other Rothamsted fields. The previous cropping may have caused the absence of leguminous plants from the Geescroft herbage, but the

difference in the grass flora, the predominance of *Aira* instead of *Dactylis*, must be due to the wetter character of the Geescroft land, and this appears to be brought about, neither by differences in the physical constitution of the soil nor by lack of drainage, but simply by the absence of carbonate of lime to coagulate the clay particles and make the mass permeable to air and water.

In any case the great contrast between the vegetation on these two pieces of land—identical in character and situation, not half-a-mile apart, on the same level—shew what large effects, both on the natural herbage and on the suitability of the soil for particular crops, can be brought about by small variations in some of the numerous factors controlling the condition of the soil and the nutrition of the plant.

THE INHERITANCE OF STERILITY IN THE BARLEYS.

By R. H. BIFFEN, M.A.,

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THE following note is concerned solely with the behaviour of certain characters in hybrid barleys which bear on the inheritance of sterility and the question whether sex is, as it seems possible, a phenomenon of gametic segregation[1]. I have used the term "sterility" in a broader sense than usual to include cases in which certain florets set no grain owing to the suppression of either the female or both the male and female reproductive organs. The plants themselves are in no cases completely sterile. The other characters occurring in the numerous varieties of barley will be considered in detail later.

At present our knowledge of the subject is naturally a meagre one, for the precise study of the phenomena of inheritance is too recent for much material to have accumulated. There is, it is true, a great deal of literature dealing with the sterility of hybrids, but it is concerned with problems which for the moment we may neglect, such as whether the existence of sterility in a hybrid was a criterion of its parents being distinct species or not. Very little of it has any bearing on its inheritance.

The more important exceptions are the crosses made by Rimpau[2] and others between "six-row" and "two-row" barleys, from which it is clear that the fully fertile "six-row" type behaves as a recessive. This has been confirmed by Tschermak[3], who has also shown that, on

[1] Since writing the above Mendel's correspondence with Nägeli has been published by Correns in the *Abhandl. d. K.S. Gesellsch. d. Wissensch., math.-phys. Kl.* XXIX. III. p. 241 from which it appears that Mendel himself was aware of this possibility.

[2] Rimpau, *Landw. Jahrb.* Bd. XX. p. 335, 1891.

[3] Tschermak, *Zeits. Landw. Versuchs. Oesterreich*, 1901, Heft II. p. 1029.

segregation occurring in the first generation from the hybrids, three "two-row" types are produced to each "six-row." Up to the present time no one seems to have called attention to the bearing of this fact on the inheritance of sterility. More recently Bateson[1] has investigated an interesting case occurring among certain sweet pea hybrids in which sterility, due to abortion of the anthers, behaves as a recessive character.

The following short account of the morphology of the inflorescences of the chief sub-species into which our cultivated barleys have been grouped will show how suitable they are for such studies.

The distinguishing characteristic of the genus Hordeum is that the single-flowered spikelets are arranged in groups of three, which alternate with one another on opposite sides of the rachis. The flowers themselves are typically hermaphrodite, as in the majority of the Gramineae. In certain sub-species of *H. sativum* the two lateral florets of the groups are staminate only and the median one hermaphrodite, whilst in another sub-species the reduction of the lateral florets is carried to a still greater extent, and, owing to the suppression of both the stamens and ovaries, the florets become sexless. In extreme cases they may be represented by the outer glumes only. The opposite type of reduction, with the stamens disappearing first, leaving a female flower, is unknown.

The first group is represented by the sub-species *H. hexastichum* and its varieties, the "six-row" barleys, and also the so-called "four-row" barleys. These latter have been grouped by Koernicke under the name of *H. tetrastichum*[2], and they are popularly supposed to have become four-rowed by the suppression of the median floret. Such, however, is not the case, for all the florets are fully developed, and the ears owe their square appearance solely to the length of the internodes and the angle at which the florets are set. Beaven more appropriately names the group *H. vulgare*[3].

Closely related to these two sub-species is the little-known group *H. intermedium*[4], containing at present only two varieties, characterised by the fact that the lateral florets, though perfect, are considerably smaller than the median ones. This forms a link between the six-row and the two-row barleys composing the sub-species *H. distichum* and *H. nutans*, which are represented more or less accurately in this country by the Chevalier and Goldthorpe varieties. In these varieties

[1] Bateson, Presidential Address, Sect. D, British Assoc. Meeting, 1904.

[2] Koernicke and Werner, *Handbuch des Getreidebaues*, p. 147.

[3] Beaven, *Journ. Fed. Inst. of Brewing*, Vol. VIII. No. 5, p. 542.

[4] *Ibid.*

the lateral florets are staminate only. It is extremely rare to find ears in which any of the laterals are hermaphrodite. I have, however, met with such cases in an unnamed variety of hybrid origin in which here and there a lateral floret gave rise to a small grain.

The extreme case in which the lateral florets are sexless or even almost completely suppressed is represented in the sub-species *H. decipiens*, a number of varieties of which are cultivated in Abyssinia. For the sake of convenience I have called this the "Abyssinian" type in the following account.

Varieties of all these sub-species have been crossed together, some in 1900, others in 1902 and 1903, and the results of combining each of these types in every possible way can now be traced. In all cases the hermaphrodite median florets only were used as parents.

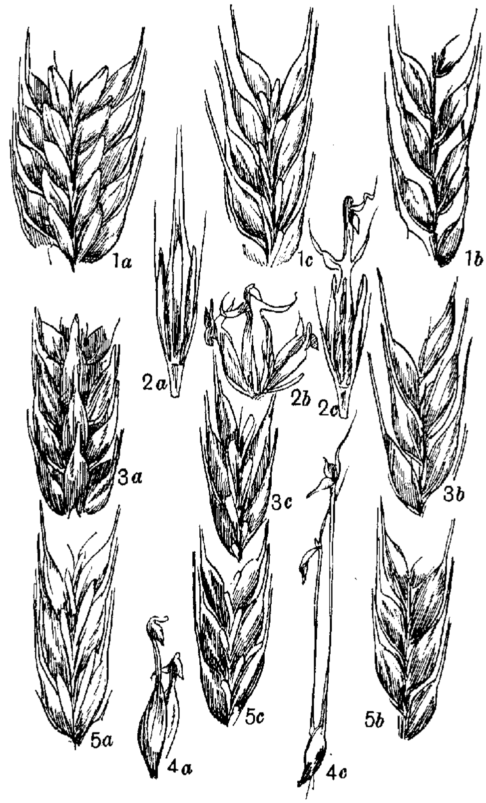
The varieties experimented with are as follows:

Six-row	*H. hexastichum*	*H. japonicum*
		H. Schimperianum
		H. pyramidatum
		H. hexasticofurcatum
		H. eurylepis
	H. vulgare	*H. violaceum*
		H. vulgare
		H. trifurcatum.
	H. intermedium	*H. transiens.*
Two-row	*H. distichum*	*H. zeocriton*
		H. inerme
		H. nigrosubinerme
	H. nutans	*H. nutans.*
	H. decipiens	*H. deficiens*
		H. Steudelii
		H. Abyssinicum.

In addition to these I have also hybridized *H. spontaneum*, a two-rowed type supposed to be the species from which our cultivated barleys have originated. Detailed descriptions of all of these varieties will be found in Koernicke and Werner's *Handbuch des Getreidebaues*. The degree of sterility in the hybrid plants (F_1) was as follows:

H. hexastichum × *H. intermedium* (six-row × six-row with smaller lateral florets); hybrid with well-developed median but smaller lateral florets.

H. Schimperianum × *H. nutans* (six-row × two-row); hybrid with staminate lateral and fertile median florets.



H. hexastichum × *H. nutans* (six-row × two-row); hybrid with staminate lateral and fertile median florets.

H. transiens (Fig. 1 *a*) × *deficiens* (Fig. 1 *b*) (six-row with small lateral florets × Abyssinian type); hybrid with fertile median florets and sexless laterals (Fig. 1 *c*).

H. spontaneum × *H. eurylepis* (two-row × six-row); hybrid with fertile median and sterile lateral florets.

H. spontaneum (Fig. 2 *a*) × *H. hexasticofurcatum* (Fig. 2 *b*) (two-row × six-row); hybrid similar in the degree of its sterility to the preceding (Fig. 2 *c*).

H. nigrosubinerme × *hexasticofurcatum* (two-row × six-row); hybrid with fertile median and sterile lateral florets.

H. pyramidatum × *H. deficiens* (six-row × Abyssinian type); hybrid with fertile median florets, but sexless lateral florets.

H. deficiens × *H. pyramidatum*, the reciprocal cross of the above, gave the same result.

H. deficiens × *H. japonicum* (Abyssinian type × six-row); hybrid of the Abyssinian type.

H. japonicum × *H. Steudelii* (six-row × Abyssinian type); hybrid of the Abyssinian type.

H. vulgare (Fig. 3 *a*) × *H. Steudelii* (Fig. 3 *b*) (six-row × Abyssinian type); hybrid of the Abyssinian type (Fig. 3 *c*).

H. Abyssinicum × *H. trifurcatum* (Fig. 4 *a*) (Abyssinian type × six-row); hybrid of the Abyssinian type (Fig. 4 *c*).

H. deficiens × *H. violaceum* (Abyssinian type × six-row); hybrid of the Abyssinian type.

H. inerme × *H. transiens* (two-row × median florets large, lateral reduced in size but fertile); hybrid median florets fertile, lateral staminate only.

H. trifurcatum × *H. nutans* (six-row × two-row); hybrid with fertile median and staminate lateral florets.

H. zeocriton × *H. nutans* (two-row × two-row); hybrid, similar to the parents with regard to the presence of sterile florets.

H. nutans (Fig. 5 *a*) × *H. Steudelii* (Fig. 5 *b*) (two-row × Abyssinian type); hybrid of the Abyssinian type (Fig. 5 *c*).

H. deficiens × *H. nutans* (Abyssinian × two-row); hybrid of the Abyssinian type.

H. Abyssinicum × *H. Steudelii* (Abyssinian × Abyssinian type); hybrid of the Abyssinian type.

The cross-bred six- and two-row barleys gave two-row barleys with staminate lateral florets similar to those of the two-row parents, but the cross-breds with the Abyssinian types as one parent and two- or six-row barleys as the other, produced lateral florets which were larger than those of the Abyssinian parent. On dissection each floret was found to consist of two feebly developed paleae, but no sexual organs were

present. It is therefore evident that the six-row type is recessive to the intermedium, two-row, and Abyssinian types, the intermedium to the two-row, and the two-row to the Abyssinian without exception. In other words, the types with completely sterile lateral florets are dominant over those with either male or hermaphrodite laterals, and the types with male lateral florets are dominant over those with hermaphrodite florets, whether fully developed or reduced in size.

The first generation from these cross-breds has still to be raised in the majority of the cases described. Where it has been grown the segregation has been of the normal type, resulting in the ratio of three of the dominant to one of the recessive forms.

Thus, for instance, *H. hexastichum* × *H. nutans* in this generation gave 193 two-rowed to 62 six-rowed, and *H. nutans* × *H. Steudelii* 85 of the Abyssinian type to 30 of the two-row type. In addition to these a hybrid of unknown descent gave 208 two-rowed and 66 six-rowed individuals.

In these cases, then, the various degrees of sterility, ranging from complete suppression of the reproductive organs in the lateral florets to reduction in size only, are clearly dominant over the perfectly developed floret.

We have now to consider cases in which certain of these types have been crossed with others bearing additional florets.

Many varieties of barley produce supernumerary florets on the paleae. These are the "kaputzen" of the German, or the "trifurcate paleae" of English systematists. They occur originally in *Hordeum trifurcatum* (Fig. 4 *a*), a barley cultivated in the Himalayas and frequently known under the name of Nepaul barley, or even Nepaul wheat[1]. The numerous varieties with trifurcate paleae described by Koernicke[2] and Beaven[3] are probably descended from this. The structure of these kaputzen has been described by Henslow[4] and by Baillon[5] in the case of *H. trifurcatum*. In this variety the awns are wanting, and their place is taken by a hood-like structure produced at the apex of the paleae, in the pocket of which a single floret is placed. The structure of the floret is peculiarly variable. Generally speaking, it consists of two paleae enclosing perhaps a solitary ovary, or one or two stamens, or sometimes a

[1] Royle, *Botany of the Himalayan Mountains*, p. 418 and Pl. 97 (*H. aegiceras*).

[2] Koernicke, *ibid.*

[3] Beaven, *ibid.*

[4] Henslow, *Hooker's Journ. of Botany*, Vol. I. p. 33, Pls. II. and III. 1849.

[5] Baillon, *Bull. de la Soc. bot. de France*, Tome 1, p. 187 (1854).

perfect hermaphrodite flower. In *H. zeocriton*, var. *densum* (Kcke) the outer palea of the supernumerary floret itself may give rise to a second floret.

These florets are as a rule sterile, but in *H. distichum*, var. *setosum*, I have frequently met with a few fertile ones, and grown plants from the grains they produced. The structure is possibly a true epiphyllous flower.

On crossing these hooded varieties with those bearing normal, *i.e.* flowerless awns, the hybrids in all cases are hooded[1], the supernumerary floret being borne either on the apex of the palea or on an awn from a half to two inches in length. Up to the present I have raised the following examples:

H. Abyssinicum × *H. trifurcatum* (hooded) (Fig. 4 *a*), hybrid (Fig. 4 *c*).

H. spontaneum (Fig. 2 *a*) × *H. hexasticofurcatum* (hooded) (Fig. 2 *b*), hybrid (Fig. 2 *c*).

H. trifurcatum (hooded) × *H. nutans*.

H. trifurcatum (hooded) × *H. Steudelii*.

In each of these hybrids the hoods are as markedly developed as in the parent forms. The first generation from the hybrids consists of individuals with hoods and individuals with awns in the ratio of three of the former to one of the latter. Thus *H. trifurcatum* × *H. nutans* (F_2) produced 71 hooded and 23 awned plants, and the hybrid of unknown parentage already referred to, 205 hooded and 69 awned plants. The first generation from the remaining hybrids has still to be raised.

Barleys with these supernumerary florets, though probably monstrous, may be regarded as more fertile than those in which they are wanting, since there is always the possibility of their setting more grain. From this point of view, then, the more fertile form is dominant over the less fertile. Lessened fertility may then be a recessive character in the barleys, so that this case would resemble to a certain extent that of the sweet peas described by Bateson, in which the sterile forms behaved as recessives. It must however be admitted that we are dealing here with a different class of phenomena.

Up to the present, then, we have evidence that sterility, using the word in the broad sense already mentioned, may be a Mendelian character in the following cases:

(1) It may appear as a recessive,

(*a*) in the sweet pea hybrids described by Bateson;

[1] Compare Rimpau, *ibid.* Tschermak, *Deutsche Landw. Presse*, 14th Oct., 1903.

(*b*) in hybrids between "hooded" and awned barleys, where the more fertile hooded form is dominant over the less fertile awned form.

(2) As a dominant character when

(*a*) fully fertile varieties are crossed with those in which the lateral florets are reduced in size but hermaphrodite;

(*b*) when crossed with varieties in which the lateral florets contain stamens only;

(*c*) when crossed with varieties with sexless lateral florets;

(*d*) where varieties with small but fully fertile lateral florets are crossed with varieties with staminate or sexless lateral florets;

(*e*) where varieties with staminate lateral florets are crossed with varieties with sexless lateral florets.

VARIATION IN COMPOSITION OF THE SWEDE.

In Mr S. H. Collins's paper in Part I he puts forward a law by which the proportion of dry matter in a given swede crop may be deduced from a formula of the type $A = k + s + v + f$, where k is a constant and s, v, and f "factors" for season, variety, and farm respectively. In his section on "verification of results," p. 96, he states that his law "must be correct...if the two sets of figures "calculated" and "found" agree with one another as well as the duplicates of actual analyses."

This seems to me rather dangerous doctrine, since from one point of view it may mean that if the experimental error be only large enough it will cover the proof of any law that may be suggested. Nor is the example quoted in the same paragraph by Mr Collins reassuring; he gives a case where $A = 11{\cdot}23 - {\cdot}06 + {\cdot}20$, and then proceeds to state that the average difference between duplicate samples amounts to 0·38. In other words, the average experimental error is nearly twice as large as one, and six times as large as the other, of the "factors" used in his calculations! Of course this may be an exceptional case, but Mr Collins's argument would be more convincing if he could give us some idea of the degree of accuracy to be expected in his various "factors." I have just worked out roughly a few cases by the usual method of least squares with the following results.

For the variety factors in the table (p. 103) for Holborn Elephant and Waterloo, the results are $0{\cdot}16 \pm 0{\cdot}105$ and $0{\cdot}20 \pm 0{\cdot}12$. For the season factor s, calculating from the mean results only as given in Table III, p. 95, I get a probable error of $\pm 0{\cdot}12$. Calculating from individual results, 1900 and 1904, the probable error becomes $\pm 0{\cdot}22$.

In one case also, for the so-called "farm factor," the relationship between Cockle Park and Eshott in 1903 appears to be

$$-\,0{\cdot}35 \pm 0{\cdot}13.$$

This would make a calculation run somewhat as follows, for, say, Holborn Kangaroo grown at Eshott in 1902 (an imaginary case),

$$A = 11{\cdot}23 + (0{\cdot}20 \pm 0{\cdot}12) + (0{\cdot}50 \pm 0{\cdot}12) + (-0{\cdot}35 \pm 0{\cdot}13).$$

Of course I may have happened upon extreme cases, but the figures seem to justify one in asking Mr Collins to review his results from the point of view of the relative magnitude of the "factors," and of the probable errors involved in their determination.

A. D. HALL.